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THE TOTAL SOLAR ECLIPSE OF AUGUST 30, 1905.

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THE last total eclipse of the sun observed was that of May 17, 1901, whose path crossed the islands of Mauritius, Sumatra, Borneo and New Guinea. Its duration, in Sumatra six and a half minutes, was the greatest of any observable eclipse of the last half century. The shadow touched the islands at very few accessible points, and the choice of observing stations was unusually limited. Nevertheless, observations were undertaken by a relatively large number of well-equipped expeditions from this country and Europe. At nearly all stations clouds of various degrees of thickness covered the eclipsed sun, and the work was seriously hampered by them. Fortunately, many valuable photographs were secured through thin clouds. For example, Professor Perrine, in charge of the William H. Crocker Expedition from the Lick Observatory, obtained results of great value with each of his ten instruments, though only five to twenty-five per cent. of the light passed through the clouds. In fact, it would be difficult to say wherein they could have been better, except that the intra-mercurial planet search was incomplete in one third of the area called for in the program.

A total eclipse, of short duration, occurred on September 20, 1903, in the southern Indian Ocean. The shadow did not pass over land, unless within the closed south polar continent, and no effort was made to secure observations.

A long eclipse will occur on September 9, 1904. It, too, will come and go practically unobserved, for its path passes eastward over the central Pacific Ocean without touching any known islands, and terminates on the coast of northern Chile about six minutes before sunset.

With the sun at such a low altitude, the atmospheric disturbances and the almost complete absorption of actinic rays will preclude the possibility of securing satisfactory observations, except perhaps as to the general form of the corona. It is known that the Chilean astronomers are expecting to view the phenomenon. Further plans do not seem to be called for.

The next observable eclipse is that of August 30, 1905. It is well situated, and will be looked forward to with unusual interest. The shadow path begins at sunrise south of Hudson's Bay, enters the Atlantic Ocean a short distance north of Newfoundland, crosses northeastern Spain, northeastern Algiers and northern Tunis, passes centrally over Assuan on the Nile, and ends at sunset in southeastern Arabia. The durations on the coast of Labrador, in Spain and at Assuan, are two and a half, three and three fourths and two and three fifths minutes, respectively.

It is none too soon to form plans for observing this eclipse. In this connection, an account of the leading eclipse problems now pressing for solution may have interest for the general reader, and perhaps some usefulness to those who will plan programs of work, though the latter will prefer a more detailed article than would be justified here.

There is probably no phenomenon of nature more beautiful and impressive than a total eclipse of the sun. Every such event is of great human interest. Even the uncivilized tribes of the earth realize, crudely, the force of the scientific fact that the sun is the origin of the light, heat and other forms of energy which make life on this planet possible.

The absorbing interest taken in eclipses by astronomers is on a broader basis. Our sun is one of the ordinary stars. In size it is perhaps only an average star; or it may even be below the average. It is the only star near enough to us to show a disk. All other stars are as mathematical points, even when our greatest telescopes magnify them 3,000-fold. The point-image of a distant star includes all its details, and it must be studied as a whole, whereas the sun can be studied in geometrical detail. Our sun is likewise the only star bright enough to supply metrical standards demanded in the study of other stars. It is not too much to say that our physical knowledge of the stars would to-day be practically a blank if we had been unable to approach them through the study of our sun. If we would understand the other stars, we must first make a complete study of our own star. Several of the most interesting portions of our sun are invisible, except at times of solar eclipse. Our knowledge of the sun will be incomplete until these portions are thoroughly understood; and this is the reason why eclipse expeditions are despatched, at great expense of time and money, to occupy stations within the narrow shadow belts.

The difficulties of solar study, in spite of comparative nearness and intense brightness, are very great. It is not generally appreciated that we are unable to study the body of the sun except by indirect methods. The interior is invisible. The spherical body which we popularly speak of as the sun is bounded by the opaque photosphere—a cloud covering composed of condensed vapors of the metallic elements. The photospheric veil, including the larger interruptions in it which we call the sunspots; the brighter areas, closely connected with the photosphere, called the faculæ; the reversing layer, a few hundred miles in thickness, immediately overlying the photosphere; the chromosphere, a shell several thousand miles thick, associated with and overlying the reversing layer; the prominences, apparently ejected from the chromosphere; and the corona, extending outward from the sun in all directions to enormous distances; these superlatively interesting features of the sun, constituting the only portions accessible for direct observation by telescope and spectroscope, are an insignificant part of its mass. They are literally the sun's outcasts. Our knowledge of the sun is based almost entirely upon a study of these outcasts. We might hope to reach safe conclusions as to the characteristics of a hermit nation by making a careful study of its banished subjects, provided the observed types correspond with types produced by our own civilization; but if new types, new customs, new forms, presented themselves, and were observable only at long range, our conclusions as to the characteristics of the country from which they were expelled would come slowly and uncertainly. It is a difficult matter to comprehend the structure and condition of any one of the sun's outcasts; the chromosphere, for example. To determine what the conditions within the body of the sun must be in order to create and maintain such an outcast shell is far more difficult.

The influence of eclipse observations upon solar and astrophysical research has been most remarkable. The reversing layer, the chromosphere, the prominences and the corona were in fact discovered at eclipses. Many of our present every-day methods of studying them are also eclipse products. The richness of eclipse results, considering the remarkably short intervals available for observation, is unique in science. To realize this, we need only recall that the durations of observable total eclipses, clear and cloudy, have amounted altogether to about one hour since the spectroscope was applied to the problem, and about half an hour since photographic methods have prevailed.

Eclipse problems relate not only to the properties of the less massive portions of the sun—everything, apparently, outside of the photospheric layer—but to the question of possible planets between the sun and Mercury. It is well known that mathematical theory, based upon Newton's law of gravitation, has not yet fully accounted for the motion

of Mercury. The perihelion of its orbit moves forward at least 40″ in a century more than theory calls for. The most plausible way of accounting for this progression has been the supposition that an undiscovered planet, or a group of small planets, exists within the orbit of Mercury. The search for such objects has been a well-defined eclipse problem; the sun-lit sky prevents effective search by every-day methods. Organized efforts to discover such bodies by visual means were made at the eclipses of the late seventies and early eighties, but they were unsuccessful. Photographic methods, though not planned for efficiency in that particular problem, were applied in the nineties. Early in the year 1900 it occurred independently to Professor W. H. Pickering, of Harvard College Observatory, and to Messrs. Perrine and Campbell, of the Lick Observatory, that efficiency in the photographic method requires the cameras to be of relatively long focus, in order to reduce the intensity of sky illumination on the photographic plate; and each of these astronomers, unknown to the other two, fixed upon the proportions which such instruments should have. Their results were in good general accordance. The first attempt to apply this method was made by Professor Pickering at the eclipse of May, 1900, with camera lenses three inches in aperture and 135 inches in focal length, but no evidence was secured. Mr. Abbot, of the Smithsonian Institution party, obtained one photograph with a similar lens, covering a limited area of the sun's surroundings, which recorded eighth magnitude stars. Four suspicious images on the plates were noticed; but whether they were ordinary photographic defects or images of real objects could not be determined, as the required second plate of the same region was not secured by this party or others.

The last word on the subject is by Perrine, who applied the method in Sumatra in May, 1901. His four telescopes, making three exposures each, secured negatives in duplicate of a region 6° wide and 38° long—19° on each side of the sun, in the direction of the sun's equator. Through thin clouds covering two thirds of this area, one hundred and sixty-two stars, including several as faint as the ninth magnitude, were photographed; and through thicker clouds covering the remaining third, eight stars, four of them between 6.0 and 6.5 visual magnitudes, were recorded. While these instruments were in use in the preceding February at the Lick Observatory, exposures were made on the region of the sky which would be occupied by the eclipsed sun in May. All objects on the Sumatra eclipse plates were recognized as known stars, by means of the February Mount Hamilton plates.

It is probable that any such planets would be well within the region covered, provided their orbit planes make a small angle with the sun's equator. The earth was very nearly in the plane of the sun's

equator on May 18—exactly in it on June 3—which was a favorable circumstance. Again, there is little probability that such bodies would be as much as nineteen degrees from the sun, and a width of six degrees would therefore allow for a considerable departure of the orbit planes from the solar equator.

Professor Perrine has deduced the following interesting results from these observations:

Before drawing any conclusions from these observations it is desirable to determine the relative brightness and size which any bodies in this region would have, by means of other members of the solar system. The asteroids seem to be best suited for this investigation, as they probably most nearly resemble the hypothetical intramercurial planet in size and condition of surface. The determination of the diameters of the four principal asteroids by Barnard [as below] renders these bodies the most suitable for such work.

Asteroid.	Visual Magnitude.	Distance, Miles.
Ceres	7.5	485
Pallas	8.5	304
Juno	9.5	118
Vesta	6.6	243
Arithmetical mean	8.0	290

The above magnitudes are those obtained at the Harvard College Observatory by photometric means. The results show such a wide range in albedo that the simple mean has been taken to represent the relations between magnitude and diameter for the group.

Assuming that the distance of the 'mean asteroid' from the earth is 153 million miles, we find that such a body, if transported to a distance of twenty-eight million miles from the sun (corresponding to an elongation distance of eighteen degrees), and seen from the earth at elongation, would be one hundred and ten times as bright. This corresponds to an increase in brightness of 5.1 magnitudes. Such a body would be relatively brighter near superior conjunction, and fainter near inferior conjunction. An intramercurial planet at the above mean distance from the sun would have to be only one tenth the diameter of the mean asteroid to appear of the same brightness.

From the dimensions and brightness of the four brighter asteroids we find that on the average one of these bodies, three hundred miles in diameter, seen at the opposition distance of the mean asteroid, would appear as of the eighth magnitude. Hence an intramercurial planet of similar constitution and thirty miles in diameter should appear as a star of eighth magnitude. If the hypothetical planet were closer to the sun, the difference of brightness and size would of course be correspondingly greater than that found above.

These observations indicate, therefore, with the exception to be noticed later, that there is no planetary body as bright as 5.0 visual magnitudes within eighteen degrees of the sun whose orbit is not inclined more than seven and one fourth degrees to the plane of the sun's equator. They further indicate that in two thirds of this region there was no such body as bright as seven and three fourths magnitude. The possible exception to be noted is that at the time of the eclipse such a body or bodies might be directly in line with the sun or with the brightest portion of the corona. The area covered by the moon's disk and corona was, however, less than one two-hundredth that of the region

searched. Owing to the increased cloudiness at the end of totality, the search is not quite complete to the fainter magnitude, yet it seems altogether probable that were there any considerable number of bodies as bright as seven and three fourths magnitude, some of them would have been detected. A planetary body thirty-four miles in diameter would, under the conditions considered, appear as a star of seven and three fourths magnitude. The total mass required to produce the change observed in the orbit of Mercury is about one half the mass of the planet. It would require, therefore, no less than seven hundred thousand bodies thirty-four miles in diameter and as dense as Mercury to equal such a disturbing mass.

From the observations detailed above it does not seem possible that sufficient matter exists in the region close to the sun in the form of bodies of appreciable size to account for the observed perturbations.

Belief in the existence of intramercurial planets has been based upon anomalies in the orbital motion of Mercury, and Perrine's work has gone far to show that the discrepancies must seek some other explanation. Had the thicker clouds not reduced the *minimum visible* in one third the area observed in Sumatra from the ninth to the sixth magnitude, it is a question whether one could recommend that this search be continued at future eclipses. However, so long as we admit that it is a question, the effort to secure definite results, positive or negative, should be made. It is not impossible that existing bodies could have been in the region of thicker clouds, or in that occupied by the moon and inner corona, or in areas outside the limits of the strip six degrees wide.

The eclipse of August 30, 1905, will occur when the earth is seven degrees from the plane of the solar equator. The maximum distance occurs September 7. It will therefore be advisable to search over a region of considerably greater width than was the case in 1901. Inasmuch as increased area means increased instrumental equipment, expense, and difficulty, a corresponding shortening of strip to be observed would perhaps be justified. It is to be hoped that observing parties well equipped for the intramercurial search will be located in Labrador, Spain, Tunis and Egypt. If clear weather prevails at any of the four stations, very valuable results may be secured. Should a new planet be observed at three such stations, the enormous interest attaching to its discovery would be heightened by the fact that its approximate orbit could be determined at once. If no planets are revealed on first class plates, the negative result would be scarcely less valuable, though certainly less interesting, than positive results; and the intramercurial question would cease to be a pressing eclipse problem.

The sun's altitude will be only 26° in Labrador and 23° in Egypt. The altitude of the lower end of the area to be photographed will be small at these stations. The atmospheric disturbances and absorption at such low altitudes will require that the exposures be lengthened. Perhaps a better plan would be for the Labrador party to cover the

entire critical region west of the sun, and only five or six degrees below it; and for the Egyptian party to cover the whole region east of the sun and only five or six degrees below it.

Eclipse observation of the sun itself concerns all that lies outside the photosphere and faculæ. While the main features of these outer volumes are for the most part quite irregular in form, yet in a general way they lie, going outward from the photosphere, in the order of reversing layer, chromosphere, prominences and corona.

The reversing layer was discovered at the eclipse of 1870 by Professor Young. It appears to consist of a thin stratum of incandescent gases, probably between five hundred and fifteen hundred miles in thickness, immediately overlying the photosphere. Its inner bounding surface seems to be quite definite and regular, but its outer surface is certainly not so. The depth of the stratum of vapor for each element composing it is probably a function of the properties and quantity of the element in question. The reversing layer is cooler than its substrata, yet abundantly hot, if isolated from its underlying strata, to produce a spectrum consisting of thousands of bright lines occupying the positions of the dark lines of the ordinary photospheric spectrum. When the moon, at the eclipse of 1870, gradually covered the photosphere, the dark-line spectrum lasted until the instant when the photosphere entirely vanished, whereupon the reversing layer was isolated, and Young observed the sudden flashing out of its bright-line spectrum. A bright line apparently replaced each dark line, and lasted perhaps two or three seconds, until the moon entirely covered the reversing stratum.

In so complex a spectrum, lasting but a few seconds, visual observations were difficult, and no records of any considerable consequence could be made. The bright-line (flash) spectrum was photographed for the first time by Shackleton at the eclipse of 1896; and several photographs of it were secured at the three succeeding eclipses, but many were defective on account of poor focusing or other cause. They confirm Young's discovery of the reversing layer, which, by the absorption of its cooler gases, introduces the dark lines in the solar spectrum. The lengths of the arcs not covered by the moon also tell us much concerning the thicknesses of the vapors of the various elements, and therefore much concerning the structure of the sun at those levels. Additional work, with more powerful instruments, in perfect adjustment, is demanded, with a view to securing better quantitative results.

Photographs of the reversing-layer spectrum, made with two, four, or more seconds' exposure, are integrated effects. Changes taking place during the exposure are lost. For this reason, it would be very valuable if a continuous record of the spectrum at one point on the limb could be secured on a plate moving in the direction of the length

of the spectrum lines. The writer obtained such photographs in 1898 and 1900, but with small instruments, not designed especially for that work; and it is hoped that improved apparatus will be available for the eclipse of 1905. There is need that flash spectra with both fixed and moving plates should be secured, since each system has its advantages and disadvantages. On moving plates the faintest lines might not be recorded, but a continuous record of changes in the strengths of lines, as the moon gradually covers the reversing strata, should be obtained.

The chromospheric stratum, overlying the photosphere, is of irregular depth, varying from four thousand to ten thousand miles. The reversing layer, to the best of our knowledge, is included in its lower strata. The prominences seem to be flame-like or explosive projections extending outward from the chromosphere; the matter in them previously and subsequently forming a part of the chromosphere. Many of the salient facts known about chromosphere and prominences were learned at eclipses; and they are still studied with some profit on such occasions. However, the spectroscopic method of observing them, devised independently by Janssen and Lockyer in 1868, has made the prominences, and to some extent the chromosphere, available for everyday study. But it must not be overlooked that, while fairly satisfactory observations of one or both subjects can be secured without an eclipse, yet the eclipse negatives are still imperatively needed to show the mutual relations of the various structures—reversing layer, chromosphere and inner gaseous corona. It is known that the prominences are larger and more numerous at sunspot maxima than at other times. The question whether the chromospheric stratum is likewise thicker and more distorted at sunspot maxima than at minima is a question for eclipse observers to settle. Observations of the continuous spectrum of prominences or chromosphere can by present methods be made only at eclipses.

The corona, perhaps the most fascinating solar feature, is exclusively an eclipse phenomenon. Various attempts have been made to observe it visually, photographically and thermally, without an eclipse; but all failed, and there seems to be no hope of success by methods now known. Any chance for even moderate success would seem to be limited to the inner portion whose spectrum contains bright lines. A daily record of this would, no doubt, be extremely valuable, but the real problem of the corona would remain unsolved.

In many respects the corona is as enigmatical as ever. A coronal photograph is the result of a projection upon and into one plane, at right angles to the line of sight, of all that remains of the sun after subtracting the volume of matter hidden by the moon. The tops of some coronal streamers, the intermediate portions of others, the bases of those near the limb and the corresponding parts of prominences

and chromosphere are all projected into one point. Whether every man who has gone forth to solve the riddle of the corona has fully realized the odds against success is doubtful.

Much has been written concerning a possible eruptive origin, or about magnetic influences in shaping the forms of its streamers. It has been shown that the details of the corona at one eclipse are totally different from those at another, and that the outline form of the corona is a function of the sun spot cycle. At sun spot maximum the general form is nearly circular, and the polar streamers are nearly as bright as the equatorial streamers. At minimum, the polar streamers are much fainter than the equatorial ones, and long wings seem to extend out approximately from the spot zones. It is a surprising fact that, with all the changes of form, we do not yet know whether the materials composing the streamers are moving in, or out, or both, or neither. The epoch-making, large-scale coronal photographs by Schaeberle in 1893 opened a promising way of determining such facts, but astronomers have been slow in taking advantage of the opportunity. Photographs of the corona should be secured for this purpose at widely separated stations—preferably at three or more stations—with essentially identical instruments, and with equivalent exposures, in order that results may be as nearly comparable as possible. This effort to determine motion in the corona, it seems to me, is the most important problem of the coming eclipse; and, fortunately, the circumstances of widely separated stations in Labrador, Spain, Tunis and Egypt, and promising weather conditions at the last three are favorable for the attack. Considering all elements of the question, including that of probable unsteadiness of the atmosphere at one or more stations, the five-inch aperture, forty-foot focus cameras, promise the most directly comparable, and therefore the best, results. The only case of motion on coronal plates thus far observed seems to be that detected by Schaeberle, on the Chile-Brazil-Africa plates of 1893; and in this instance the moving mass was decided to be a comet, and not a part of the real solar appendage.

One of the most intensely interesting features ever observed in the corona was the tremendous funnel-shaped disturbance recorded on the Sumatra plates of 1901. Perrine was able to show, with essentially no room for doubt, that the vertex of the disturbance was immediately over the large and only sun spot visible on the sun in the week preceding and the week following the eclipse. The circumstances were unusually favorable for reaching this conclusion: there was but one sun spot; it was very near the limb at the time of the eclipse; there was but one region of unusual disturbance visible in the corona; this was on an extraordinarily large scale, and its vertex was near the sun's limb; and the disturbance and the sun spot had identically the same

position on the sun's limb. It was exceedingly unfortunate that three cameras of the forty-foot pattern could not have been working in harmony, at three stations widely separated, to determine what changes, if any, were taking place in the disturbed coronal area. Under excellent atmospheric conditions, cameras still larger than those referred to should record more minute details of coronal structure, and thus lead to valuable results; but such observations would reach their full value only in case comparisons could be instituted with photographs taken under similar conditions at distant stations. However, as already stated, cameras of the forty-foot pattern give greater promise of cooperative usefulness, taking into account the average atmospheric conditions which must be expected at some of the stations.

The spectra of recent coronas have led to most interesting results. They leave no doubt that, at those eclipses, the spectrum of the inner corona contained no perceptible dark lines. Perrine's Sumatra photographs seem to establish that the spectrum of the great outer portion is substantially a copy of the solar spectrum. The simplest interpretation of these observations is that the outer corona is largely composed of minute particles which reflect and diffract the sunlight falling upon them, whereas the portions near the hot solar surface are mostly incandescent, shining by their own light. Polarigraphic observations are in harmony with this theory. Opposed to the idea of the incandescence of the inner corona stands, alone, the thermographic observations by Abbot in 1900, of a corona less hot than the instrument with which he worked. While it is difficult to assign such a low temperature to particles near the solar surface, and one should perhaps look for other interpretations of the thermographic results, yet there is an urgent demand for a repetition of all the preceding observations bearing upon the nature of the corona.

The polarigraphic observations of recent coronas have been very interesting—leading to the knowledge that the light of the corona is strongly polarized, except, apparently, in close proximity to the sun's surface; and strengthening the view that the corona is very largely composed of minute particles of matter which receive their light from the photosphere. Unfortunately, the photographs do not permit the making of quantitative measurements of the amount of polarization in and across the solar radii; and future programs for eclipse observations in this line should make provision for securing comparable unpolarized coronal images for standards of reference.

Special interest will be taken in determining whether the comparatively shallow inner stratum of the corona which yields a bright-line spectrum, is more extensive at the sunspot maximum of 1905 than it was at the minimum of 1898–1901. The chances are that it will be both thicker and more uniform in thickness. Should it be brighter

than at recent eclipses, the opportunity to search for new coronal bright lines will be excellent.

The accurate wave-length of the principal coronal bright line, near λ 5303, should be determined. A modern spectrograph, holding three dense flint prisms, should make the problem easy. The accurate wave-lengths of all truly coronal lines should be determined as rapidly as possible, partly in order that a serious effort may be made to represent them by a simple common law, as has been done for hydrogen and helium.

Of many other eclipse problems—the photometry, the shadow bands, etc.—it need only be said that accurate observations will prove very useful.

The tendency of recent eclipse work is toward a unification of the problem. The main divisions of the sun's structure are no longer to be studied separately. Close connection has been observed between spots and faculæ; between photosphere and reversing layer; between sun spot and coronal disturbances; between coronal streamers and prominences; between prominences and chromosphere; between the sunspot curve and the form of the corona; and in other ways the unity of the problem is emphasized. This is only what we should expect, for all these outward and visible features of the sun must be related products of the stupendous forces at work within its body. In reality, all observations of the sun, whether those made daily at fixed observatories or those secured at eclipses, bear upon the solution of one problem: the structure, composition and condition of the sun, from its center to the outermost limits of the coronal streamers.

It is well known to eclipse observers that a regrettably large proportion of observations of these phenomena are failures, or are but partially successful. Some of these unfortunate outcomes are due to nervousness at the critical moment; a psychological state of which some observers know nothing, and against which others are unable to contend. It is a mistake to invite nervousness by attempting to do too much in the limited duration of totality. If seven photographs can be secured with one instrument, working with moderate speed in changing plates, an attempt to secure eight by working under high nervous tension would be a serious error. However, the most prolific source of failure is that of new instruments and new methods used for the first time on eclipse day. It is not an uncommon practise to delay preparations until a few months or weeks before expeditions must depart for their stations; to order new instruments, or new parts of instruments, just in time to have them shipped from factory to station; to use new methods of focusing, etc., for the first time, at the station; and to leave insufficient time for the rehearsal of program after the instruments are in supposed adjustment. It is unnecessary to say that this is cul-

pable management and all wrong. Every piece of apparatus should be set up, adjusted, tested and used at the home station; and time should be available thereafter for making modifications in apparatus, methods and program, and for retrial. With every possible preparation made before leaving home, the astronomer will find his time occupied at the eclipse station in solving the ninety and nine local problems whose coming is sure, but whose nature can not be foreseen. To install half a dozen instruments in a fixed observatory so that they will work satisfactorily, one at a time, and at the observer's leisure, is not a small problem. To construct a temporary observatory in an out of the way corner of the earth, to mount the eight or ten instruments, and to train the dozen or more assistants so that all the instruments and all the men will work together satisfactorily at the fixed instant of totality, is a problem of a very different order. The point which I wish to emphasize is that preparations for observing the eclipse of August, 1905, should begin early in 1904.

COPERNICUS.

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NICOLAUS COPERNICUS was born in Thorn, a town of Prussian Poland, on February 19, 1473. His father, Niklas Koppernigk, was a merchant of Krakau who established himself in Thorn about 1450, and there married Barbara, the daughter of Lucas Watzelrode, a descendant of an old patrician family. The father was chosen alderman in 1465—a testimony of his worth. He had four children: Barbara, who died abbess of the Cistercians at Culm; Katherina, who married a merchant of Krakau; and two sons, Andreas and Nicolaus.

We know little of the childhood of Nicolaus. In 1483 his father died and he was placed in the care of his uncle, another Lucas Watzelrode, who was called to be bishop of Ermeland in 1489, and with whose career that of Copernicus is closely bound up. The boy was educated in Thorn till his nineteenth year, when he was placed in the University of Krakau. The greatest illustration of its faculty was Albertus Blar de Brudzewo (usually written Brudzewski), professor of astronomy and mathematics. The works of Purbach and of Regiomontanus were expounded in his lectures. In the winter semester of 1491–92 Copernicus was matriculated in the faculty of arts, and devoted himself, so it is recorded, with the greatest diligence and success to mathematical and astronomical studies, becoming, at the same time, familiar with the use of astronomical instruments. In the autumn of 1494 Brudzewski left the university, and it is probable that Copernicus did the same. The humanists of the faculty had suffered a defeat at the hands of the scholastics, and the latter now ruled supreme. At Krakau Copernicus studied the theory of perspective, and applied it in painting. Portraits from his hand are praised by his contemporaries.

In the summer of 1496 the youth went to Italy, and in January, 1497, he was inscribed at the University of Bologna, in the 'Album of the German Nation,' as a student of jurisprudence. From 1484 to 1514 the professor of astronomy at Bologna was Dominicus Maria da Novara. He was an observer, a theorist, as well as a free critic of the received doctrines of Ptolemy, although such of his criticisms as we know are not especially happy, it must be confessed. He determined the obliquity of the ecliptic to be 23° 29′ by his own observations, which is in error by 1′ 20″ only, a small quantity for his time. Coper-

nicus was received by him on the footing of a friend and helper, rather than as a pupil; and the association was, without doubt, of great benefit to the younger man. All the systematized knowledge of the time was opened to him; what was known was examined and discussed, not received uncritically. Best of all, observation was practised as a test of theory and as the only basis for its advancement.

The first recorded observation of Copernicus is an occultation of *Aldebaran* by the moon in 1497 at Bologna; in 1500 he observed a conjunction of Saturn with the moon at the same place, and a lunar eclipse at Rome. Other eclipses were observed in 1509, 1511, 1522 and 1523; and positions of Venus, Mars, Jupiter and Saturn in 1512, 1514, 1518, 1520, 1523, 1526, 1527, 1529, 1532, 1537. These recorded observations extend over a period of forty years. Though they are few in number, there is no reason to doubt that they are merely excerpts from a more considerable collection. They were made with very simple wooden instruments constructed by the observer's own hands. One of them, a *triquetum,* was sent as a present to Tycho Brahé in 1584, forty-one years after the death of Copernicus. It was made of pine wood, eight feet long, with two equal cross arms. They were divided, in ink, into 1,000 equal parts, and the long arm into 1,414 parts. This precious relic, together with a portrait of Copernicus, was long preserved in Tycho's observatory at Uraniborg, and finally removed to Bohemia, where it perished in the confusions incident to the Thirty Years' War (1618–48).

Rheticus once urged upon him the need of making astronomical observations with all imaginable accuracy. Copernicus laughed at his friend for being disturbed about so small an error as a minute of arc, and declared that if he were sure of his observations to ten minutes, he would be as pleased as was Pythagoras when he discovered the properties of the right-angled triangle. Copernicus determined the latitude of Frauenburg to be 54° 19½′, which is 2′ too small. This seems to us a large error. Even with his instruments he could have been more precise if he had repeated his observations many times. But the determination was excellent for the times, as we may see by remembering that the latitude of Paris was given by Tycho as 48° 10′, by Fernel as 48° 40′, by Vieta as 48° 49′, by Kepler as 48° 39′. His calculated longitude of *Spica Virginis,* which he took as a standard star, was 40′ in error. He concluded that Krakau and Frauenburg were on the same meridian—an error of 17½′ of arc. The observations of Albategnius, five centuries earlier, were far more precise, and this was not entirely owing to the superiority of the Arab instruments.

At the University of Bologna Copernicus mastered Greek. The knowledge was subsequently utilized in a translation into Latin of the epistles of Theophylactos Simokatta (630 A. D.), which he printed in

1509. This was the only work published by him in his lifetime. The translation is said to be elegant, but the book itself is of comparatively little importance. He had studied it at the university and utilized his knowledge. The book upon which his fame rests—'De Revolutionibus Orbium Cœlestium'—did not appear until the very day of his death, and was published by the care of others. Scipione dal Ferro, the discoverer of the general method of solving the cubic equation, was in residence at Bologna at the same time, and there is little doubt that Copernicus met him also, although there is no record of the meeting. In recording this name we seem to be well out of the middle age. A general solution of the cubic belongs to the modern period, although the Arabs were working on the question in the tenth century.

In 1497 Copernicus was appointed Canon of Frauenburg, which assured to him, for life, an income corresponding to about $2,250 of our money of to-day, and a leave of absence of three years was granted him to continue his studies in Italy. At a later date he also received a sinecure appointment at Breslau. He had already taken the lesser vows; to the higher he never was dedicated. In 1499 his brother Andreas was likewise consecrated Canon of Frauenburg, and he also matriculated at Bologna (1498) in the faculty of law. Both brothers were represented at home by substitutes, and considerable expense may have attached to this, but it is curious to note that on account of the 'costly living' at the university they needed, and received, remittances from the bishop, their uncle.

In the summer of 1500 his leave of absence expired, and in company with his brother he crossed the Alps to Frauenburg, where both received a new permission to return to Italy. It was stipulated that Nicolaus should study medicine after the completion of his courses in law, in order that he might serve as physician to the Frauenburg chapter. In the autumn of 1501 both brothers were again in Italy, Andreas at Rome, Nicolaus at Padua. The doctor's degree in jurisprudence was conferred upon Nicolaus in 1503, but he remained in Italy till the year 1505 or 1506—nine or ten years in all.

In the archives of Ferrara we read:

1503. Die ultima mensis Maij. Ferrarie in episcopali palatio, sub lodia horti presentibus testibus vocatis et rogatis Spectibili viro domino Joanne Andrea de Lazaris siculo panormito almi Juristarum gymnasii Ferrariensis Magnifico Rectore, Ser Bartholomeo de Silvestris, cive et notario Ferrariensi. Ludovico quondam Baldassaris de Regio cive Ferrariensi et bidello Universitatis Juristarum civitatis Ferrarie, et alijs.

m: **Venerabilis, ac doctissimus vir Nicholaus Copernich de Prusia Canonicus Varmensis et Scholasticus ecclesie S. crucis Vratislaviensis: qui studuit Bononie et Padue, fuit approbatus in Jure canonico nemine penitus discrepante, et doctoratus per prefatum dominum Georgium Vicarium antedictum etc.**

promotores fuerunt
D. Philippus Bardella et
D. Antonius Leutus qui ei dedit insignia } cives Ferrariensis etc.

In the year 1500 Copernicus delivered lectures at Rome before an audience of two thousand hearers, the Archbishop of Mechlin declares. These lectures could not have announced the heliocentric theory, which dates from the year 1506 only, nor could they have been before the university, because Copernicus did not take the degree that admitted him to the privilege of teaching until 1503. He took no degree at Krakau, so far as is known.

Copernicus was now quite free to prosecute his studies in medicine, which he combined with philosophy. The celebrated Pomponazzi was then a member of the faculty, in the prime of his vigor. He had taken his degrees in philosophy and medicine at Padua in 1487, and in the next year, when he was but twenty-six years of age, had been chosen extraordinary professor. It was a custom of those days to choose two professors of each subject in order that their public disputations might stimulate their hearers to independent thinking. The ordinary professor of philosophy was Achillini—a veteran of the strict school of Aristotle.

Pomponazzi remained at Padua until the university was closed in 1509; and in Ferrara till 1512, when he removed to Bologna, where in 1516 he wrote his famous treatise on the 'Immortality of the Soul'—the foundation of his character as a skeptic and of his fame as a philosopher. Into his doctrines it is not necessary to enter at length. Briefly they are that man, standing on the confines of two worlds—the material and spiritual—necessarily partakes of the nature of both. Man is partly mortal (since the human soul depends in some degree on matter) and partly immortal. The soul is, Pomponazzi says, absolutely mortal, relatively immortal. This doctrine was, of course, a denial of the theory of the Roman church. He was vehemently attacked. His book was burned in Venice. Powerful friends among the cardinals protected him in Rome. His university stood by him and confirmed him in his professorial chair for eight years, and increased his salary to 1,200 ducats.

Pomponazzi was a thinker of essentially modern spirit. Reason, he said, was superior to any authority. If, in his teaching of Aristotle, he should find himself in error, "ought I," he says, "to interpret him differently from my real sentiment? If it is said—the hearers are scandalized—well, be it so. They are not obliged to listen to me, or to forbid my teaching. I neither wish to lie, nor to be false to my true conviction." He decides, on psychological grounds, against the immortality of the soul, and then proceeds to build up a system of

practical ethics resting on philosophy. Belief is not needed as a basis for ethics—not by cultured men, at any rate. He is the first writer within the christian communion to attempt to establish morality on a foundation of reason. He is a Stoic. "The essential reward of virtue is virtue itself," he says; "the punishment of the vicious is vice, than which nothing can be more wretched and unhappy." Future rewards and punishments are not invoked.

It is worth our while to pause here and reflect that we are hearing a teacher to whom Copernicus listened; to whom all Italy, nay all Europe, attended. This teaching was permitted in Italy. It influenced thousands upon thousands of hearers. Perhaps the tolerant treatment of Lutherans in Ermeland by Copernicus when administrator of his diocese may have had its origin in ideas received at this time.

There were other men in the faculty with a message for pupils of genius. Aristotle and Plato were expounded from original Greek texts, and the mazy fabrics of the commentators were swept away. Fracastor, who was, by and by, to become an opponent of the heliocentric theory, was a teacher there. He was the first to teach that the obliquity of the ecliptic changed uniformly (1538), in which respect—only—his doctrine was more sound than that of Copernicus. Medicine was expounded by four professors, and dissection of the human body was practised. Marc Antonio della Torre, the instructor of da Vinci, was one of the anatomists. So far as is known, Copernicus did not take his doctor's degree in medicine.

He was, however, skilled in physick, after the fashion of his day, and practised the art during all his life. He was considered, some of his biographers say, 'a second Æsculapius.' We know nothing definite of his medical practise until his later years. From 1529 to 1537 he treated Bishop Ferber, who praises him as the preserver of his life. Duke Albrecht of Prussia called him to Königsberg in 1541 to treat one of his court, and it is of record that the patient recovered.

It does not appear that Copernicus returned to Frauenburg before 1506. He was then thirty-three years of age. All that the world had then to offer in the way of culture was his. He had followed university studies in theology, philosophy, logic, medicine, mathematics and astronomy. He had mastered Greek, and practised painting. He had been the friend or pupil of the greatest teachers of Italy for ten years, and was now established as physician to his uncle in the bishop's palace at Heilsberg, in high station, with an assured income. Up to this period he had shown no original power; but there can be no doubt that he was universally regarded as a man of the highest culture.

His relation to his uncle was that of Achates to Æneas, affectionate

and intimate. The bishop of Ermeland was a great noble in a place of power. Affairs of much import to the church had to be treated. The knights of the Teutonic order (founded at Acre in 1190) had conquered the Duchy of Prussia in the thirteenth century. West Prussia had been ceded to Poland in 1466, while East Prussia, including Ermeland, was a Polish fief. A part of the policy of the order was to extend the lordship of their metropolitan Bishop of Riga over the diocese of Ermeland. It was the policy of Bishop Lucas to oppose all such efforts, to attain entire independence, and even to become spiritual over-lord of a part of the territory of the Teutonic order. These plans came to nothing; but a legacy of hatred remained among the knights, who left nothing undone to provoke and degrade the Ermeland bishop and his friends, and to excite disorder in his own territory. The pressure of the invading Tartars on the borders kept the knights occupied, however, and left them little leisure for hostile action. Constant vigilance was required on the part of the bishop, and many journeys to different parts of the bishopric were required.

Copernicus was charged with missions of this sort from the very first. It was during one of these journeys to Petrikau in 1509 that he printed his Latin version of the 'Epistles' of Theophylactos. Greek epistles—invading Tartars—feudal rights—church privileges—Polish and Prussian politics—these were the preoccupations of his mind. We can hardly think that much time was left for astronomy, yet the lunar eclipse of June 2, 1509, was duly observed. One of Copernicus's biographers calls him 'a quiet scholarly monk of studious habits—in study and meditation his life passed—he does not appear as having entered into the life of the times.' This is the legend. It is obviously only a small part of the truth. In March, 1512, the bishop of Ermeland died and Copernicus returned to his cloister at Frauenburg. He was now thirty-nine years old.

In the dedication of his 'De Revolutionibus' to the Pope (1542), Copernicus says that it is now 'four nines of years' since the heliocentric theory was conceived. Strictly interpreted this brings the date of its birth to 1506. It is, at all events, safe to say that the idea was elaborated on German, though it may have been born on Italian, soil.

From 1512 to 1516 Copernicus was in constant residence at the Cathedral of Frauenburg, where indeed the greatest part of his life was spent. For two periods (1516–19 and 1520–21) he lived at Allenstein, administering certain estates belonging to his chapter. His observatory was on one of its towers and commanded a wide horizon. Few observations were necessary for his great discovery of the heliocentric motion. He knew beforehand the phenomena to be explained. Ptolemy had offered a solution that had been accepted for fourteen

hundred years. Would any other hypothesis explain them? In the first place, Copernicus affirms the rotation of the earth on its axis. The rising and the setting of the stars is caused by this.

The question of the rotation of the earth had been examined by Ptolemy. He rejects the notion, saying: "If the earth turned in twenty-four hours around its axis every point on its surface would be endowed with an immense velocity, and from the rotation a force of projection would arise capable of tearing the most solid buildings from their foundations and of scattering their fragments in the air." The force of projection depends, we know, not only on the absolute velocity of points on the turning earth (and this velocity is immense), but also on the angular velocity about this axis. The latter is slow. The hour hand of a clock turns twice as fast as the earth. The projective force at its maximum is just sufficient to diminish the weight of a ton by six pounds. A feeble force of the sort is not fitted to tear trees up by their roots or buildings from their foundations, as Ptolemy supposed.

Copernicus adopted the theory of a rotating earth, although he was no better able than Ptolemy to explain the difficulty. The science of mechanics was not born till the time of Galileo. The reasoning of Copernicus is: "The rotation of the earth being a natural movement, its effects are very different from those of a violent motion; and the earth, which turns in virtue of its proper nature, is not to be likened to a wheel that is constrained to turn by force." He seeks to escape the difficulty by a trick of scholastic philosophy. No other issue was open in his day. Examples of this sort are well fitted to give us a vivid idea of the state of science in those times. It was not easy for our predecessors to take a forward step. More honor to them that the steps were taken.

In the preface to the 'De Revolutionibus' Copernicus declares that he was dissatisfied with the want of symmetry in the theory of eccentrics and weary of the uncertainty of the mathematical conditions. Searching through the works of the ancients, he found that some of them held that the earth was in motion, not stationary. Philolaus, for example, taught that the earth revolved about a central fire.* Copernicus makes no mention of the theory of Aristarchus. We must assume that he did not know it, though his ignorance in this respect is hard to explain. We have no list of his library, which was, however, extensive for the time.

"Then I too," says Copernicus, "began to meditate concerning the motion of the earth; and although it appeared an absurd opinion, yet since I knew that, in earlier times, others had been allowed the privilege of imagining what circles they might choose in order to explain

* The central fire of Philolaus was, however, not the sun; for in his theory the earth, the sun, the moon and all the planets revolved about a fire so placed at the center of the system as to be forever invisible to the earth.

the phenomena, I conceived that I also might take the liberty of trying whether, on the supposition of the earth's motion, it were possible to find better explanations of the revolutions of the celestial orbs than those of ancient times. Having then assumed the motions of the earth that are hereafter explained, by long and laborious observation I found at length that if the motions of the other planets be likened to the revolution of the earth, not only their observed phenomena follow from the suppositions, but also that the several orbs, and the whole system, are so connected in order and magnitude that no one part can be transposed without disturbing the rest and introducing confusion into the whole universe." He looked, he here says, for a new theory because the old one was unsymmetric; and his new theory satisfies because it consistently explains the facts of observation and because it was symmetric. Symmetry of the kind referred to is not essential to a true theory. If any theory explains every fact of observation quantitatively as well as qualitatively, it is to be accepted. Copernicus was not free from hampering presuppositions any more than his predecessors.

"We must admit," he says, "that the celestial motions are circular, or else compounded of several circles, since their inequalities observe a fixed law, and recur in value at certain intervals, which could not be unless they were circular; for the circle alone can make that which has been recur again." In writing this passage his mind was closed to every idea but one. Copernicus knew, far better than most of us, that ovals and ellipses might also serve to represent recurring values, but the thought did not even cross his mind in connection with celestial motions. He was committed to circular motions exclusively, from the outset.

"We are therefore not ashamed to confess," he says, "that the whole of the space within the orbit of the moon, along with the center of the earth, moves around the sun in a year among the other planets; the magnitude of the world (solar system) being so great that the distance of the earth from the sun has no apparent magnitude (is indefinitely small) when compared with the sphere of the fixed stars. . . . All which things, though they be difficult and almost inconceivable, and against the opinion of the majority, we, in the sequel, by God's favor, will make clearer than the sun, at least to those who are not ignorant of mathematics."

The system of Copernicus required thirty-four circles and epicycles —four for the moon, three for the earth, seven for the planet Mercury and five for each of the other planets. Cumbrous as this apparatus appears to us, it was a distinct simplification of the Ptolemaic system as taught in the sixteenth century. Fracastor, writing in 1538, employed sixty-three spheres to explain the celestial motions.

One word must be said of the theory of *trepidation* which Coper-

nicus accepted. The precession of the equinoxes was discovered by Hipparchus by comparing his own observations of stars with preceding ones. He saw that the longitudes of the stars changed progressively and fixed the annual change as 1° in seventy-five years. Later observers determined the amount of precession by comparing their own observations with preceding ones. The motion of the origin of longitudes—the equinox—is really uniform. An unlucky Jew—Tabit ben Korra—in the ninth century, came to the conclusion that the motion was not uniform, but variable, sometimes at one rate, sometimes at another. The variable motion was the trepidation. Copernicus admitted the reality of this phenomenon and thereby introduced a fault. Tycho Brahé, who had no important data on this point that was inaccessible to Copernicus, rejected the idea of trepidation and freed astronomy from a blemish that had endured for centuries.

It is impossible and unnecessary to exhibit in this place the details of the heliocentric theory of Copernicus. In Kepler's account of Copernican astronomy there is a section on the explanation of the retrogradations of the planets. "Here," he says, "is the triumph of the Copernican astronomy. The old astronomy can only be silent and admire; the new speaks and gives rational account of every appearance; the old multiplies its epicycles; the new, far simpler, preserves everything by the single motion of the earth around the sun." In describing the stationary points of the planets he declared: "Here the old astronomy has naught to say."

We must try to put ourselves in the place of the students of those days who heard the two explanations of the world—the geocentric and the heliocentric—expounded by the same professor in the same lecture-room as alternative hypotheses. Each hypothesis offered a possible explanation. That of Copernicus was so simple that its intellectual acceptance was immediate. It was possible; but was it true? If it were accepted, what implications did it bring in its train? The real difficulty was moral, not intellectual. Was the whole edifice of Ptolemy to be destroyed? No—some of it was indubitably true. If some, why not all? What was to become of the authority he had held for a thousand years? Was all knowledge to be made over? Even the idea that part of the 'Almagest' was true and part false was not to be lightly accepted.

The conception that every physical problem has one and only one solution was also entirely new; until it was fully received students balanced one explanation against another, and even held two at once, strange as this may seem to us with our new standards in such matters. The heliocentric theory eventually prevailed not because the logic of Ptolemy was broken down, but because all mere authority was weakened. The dicta of philosophers were looked at in a new light. It was

not, in fact, generally received until the day of Newton, though it was sufficiently established by the observations of Galileo and convincingly by the calculations of Kepler. To actually demonstrate the rotation of the earth on its axis we must have recourse to an elaborate experiment like that of Foucault on the pendulum, or to comparisons of the force of gravity in different latitudes; to demonstrate its revolution round the sun it is necessary to measure the time required for light to reach us from the distant planets, or to evaluate the aberration of the light of the fixed stars. It was not easy for the sixteenth century to make a decision. If the heliocentric theory were true, then the planet Venus must show phases like the moon; but no phases could be seen. It required Galileo's telescope to show them. Moreover, the fixed stars must have annual apparent displacements in miniature orbits. None such were visible; none were detected until 1837, when Bessel determined the parallax of a fixed star (61 *Cygni*) for the first time. Galileo sought for them in vain; so did Herschel; so did other astronomers of the eighteenth century with their splendid instruments. The conception of epicycles was retained in the 'De Revolutionibus,' and it seems to us a blemish; to the contemporaries of Copernicus it was a mere analytic device. Newton explains one of the inequalities of the moon's motion by an epicycle, in the 'Principia.'

It is only when we thus consider in detail how the new ideas must have presented themselves to the students of the sixteenth century that we can comprehend the real obstacles in the way of their acceptance. A genius like Kepler could receive them simply on their intellectual merits. Men in general required time to change their point of view, and to accept a novel and essentially disheartening theory. Ptolemy's system of the world was compendious, comfortable, so to say, and easily understanded of the people. Man's central position in the universe flattered his pride and allayed his fears.

Peter the Lombard (1100–60) expresses the accepted view in its baldest form: 'Just as Man is made for the sake of God, that is, that he may serve him, so the Universe is made for the sake of Man, that is, that it may serve him; therefore is Man placed at the middle point of the Universe, that he may both serve and be served.' The new view made man an outcast and placed him in immense and disquieting solitudes. Pascal has phrased the new and anxious fear: 'Le silence éternel de ces espaces infinis m'effraie.'

Astronomers needed accurate tables of the planetary motions in order to predict eclipses and conjunctions. The Alphonsine tables were quite unsatisfactory. The theory of Copernicus was made the basis of new tables—the Prutenic tables—by Reinhold in 1551, and they remained the standard until 1627, when the Rudolphine tables, based on Kepler's theories and Tycho's observations, superseded them.

The doctrines of Copernicus were spread by means of almanacs based upon Reinhold's tables rather than by his theoretical works; and they made their way quietly, surely and without any great opposition. Tycho proposed a new (and erroneous) system of the world in 1587. It also had its effect in weakening the authority of Ptolemy. The motions of comets began to be observed with care. It was clear that the doctrine of material crystal spheres would not allow room for their erratic courses. In one way and another the authority of the ancients was broken down and the way prepared for the eventual triumph of the theory of Copernicus.

It is interesting to note the opinions of Englishmen of the sixteenth and seventeenth centuries. Francis Bacon rejected the new doctrines; Gilbert of Colchester, Robert Recorde, Thomas Digges and other Englishmen of the time of Queen Elizabeth, accepted them. Milton seems to hesitate in 'Paradise Lost' (book viii.), which was written after 1640, though he had visited Galileo in Florence in 1638, where, no doubt, Galileo proved the Copernican theory to him by word of mouth. At all events he thoroughly understood it as his description of the earth

> *. . . that spinning sleeps*
> *On her soft axle, while she paces even*
> *And bears thee soft with the smooth air along,*

abundantly proves, since in the last line one of the chief objections to the theory is answered.

The heliocentric theory gained powerful auxiliaries in Moestlin, professor of astronomy at Tübingen, and in his pupil Kepler. In 1588 Moestlin printed his 'Epitome,' in which the mobility of the earth is denied; but he accepted the new views probably as early as 1590. Kepler writes: "While I was at Tübingen, attending to Michael Moestlin, I was so delighted with Copernicus, of whom he made great mention in his lectures, that I not only defended his opinions in our disputations of the candidates, but wrote a thesis concerning the first motion which is produced by the revolution of the earth." In 1596 Moestlin, in a published epistle, expressly adhered to the heliocentric theory of the world.

Luther emphatically declared his opinion of the Copernican theory on several occasions. He calls Copernicus 'that fool' who is trying to upset the whole art of astronomy; and refers to Joshua's command that the sun should stand still as a proof that the earth could not possibly be the moving member of the system. Melanchthon, a far more learned man, declared that the authority of scripture was entirely against Copernicus. The attitude of the Roman Church was more indifferent at that time, not more tolerant. Tolerance comes with enlightenment; and both protestant and catholic doctors were, in gen-

eral, profoundly ignorant of science. When we are thinking of the attitude of the church we must remember that the conflict with Galileo had not arisen. Calvin quotes the first verse of the ninety-third Psalm

—The world also is established, that it can not be moved

and says: 'Who will venture to place the authority of Copernicus above that of the Holy Spirit?'

Such dicta of great theologians are often quoted to demonstrate the existence of an age-long conflict between science and religion. So to interpret them is a sad misconception of the real warfare that has occupied mankind for ages. The veritable conflict has been between ignorance and enlightenment, not in one field only, but in all conceivable spheres.

Before there can be fruitful discussion the 'universe of discourse' must be defined. Things of a like kind can alone be compared. The world of science relates and refers to material things moved by physical forces; and only to these. The world of religion relates and refers only to immaterial things moved by spiritual energies. These worlds are wide apart now. They were widely separated even in the sixteenth century, and they were entirely divided for the highest thinking men even in the middle ages. In either world conflicts are possible. They can only take place between ideas of the same kind; between religion and heresy, or between science and pseudo-science. Theologians decide the issue in one world; men of science in the other. It is the business of philosophers to define and discuss the limits of each world in turn; to determine the validity of conclusions. It is the privilege of poets harmoniously to express imagined analogies between the action of spirit on spirit and of force on matter. It is the dream of seers and prophets to synthesize such analogies into a single system, mingling two universes into one. Whatever may be our hope for the future, the synthesis has not yet been achieved. Theologians have essayed it from one direction, philosophers from another, but the essential distinction remains untouched. There is a world of matter; there is a world of spirit. Men live in both. Their actions are ruled by different and discrepant laws. In the world of spirit the good man is safe and happy, no matter what fate may befall him in the world of physical phenomena. In the latter world no virtue will save the man who transgresses its especial laws. Gravitation, and not goodness, decides whether his falling body suffers harm or is preserved alive.

To Calvin the pronouncement of Copernicus was sheer blasphemy. It seemed to him to lie entirely within the sphere of religion. Judged by the accepted standards of that sphere it was audacious heresy. To Kepler the law of Copernicus lay entirely within the sphere of science. It was to be accepted as true, or rejected as pseudo, science entirely by

scientific criteria. Calvin's words fell within one universe of discourse, Kepler's in another. There was no conflict between religion and science as such. Calvin sat as judge of a conflict between religion and a possible heresy. Kepler asked himself if this new assertion was substantial truth or merely error masquerading in a scientific form. Phenomena can not be judged by criteria belonging to a world to which they are foreign. It is in a light like this that we must examine the relations of such men as Copernicus and Galileo to their times.

The Lateran council (1512–17) appointed a committee to consider the much needed reform of the Church calendar, and in 1514 the help of Copernicus was asked—a proof that he was not only remembered in Rome, but that his reputation had grown since his residence there. He declined to give advice, for the reason that the motions of the sun and moon were, as yet, too imperfectly known. At the request of the chief of the committee, Copernicus continued his researches on the length of the tropical year—a fundamental datum.

In November, 1516, the quiet life of Copernicus at Frauenburg was broken up by his appointment as *Administrator bonorum communium* at Allenstein. The appointment was for one year, but the administration of Copernicus was so successful that he occupied the post during the years 1516–19 and again in 1520–21. His manifold duties in this place brought him again into conflict with the Teutonic knights. The interests of the order and of the church in Ermeland were totally antagonistic. At times open hostilities occurred and towns were besieged, taken and plundered. It is not necessary to follow this harassing strife into the details of Prussian and Polish politics. It is recounted in history as the *Fränkischer Reiterkrieg*. In 1521 Copernicus, then the recognized head of his chapter, was selected to draw up a statement of grievances against the order to be laid before the estates of Prussia. The lands of the chapter of Frauenburg had been overrun, the towns and villages plundered, the peasants had fled or had been killed. The castle of Allenstein, the residence of Copernicus, was itself in danger until it was saved by a four years' truce concluded at Thorn. In such stormy times astronomy was not to be thought of.

It was at this period that Copernicus composed, at the request of the Prussian estates, a memorial on the debasement of the coinage of the country and on the remedies to be adopted. "Money," he says, "is a measure, and like all measures it must be constant in value. What would one say to a yard or a pound whose values could be changed at the will of the measure-makers? The value of money depends not on the stamp it bears, but on the value of the fine metal it contains." Nothing could be clearer than this. His conclusions on the effects of a debased currency on the interests of landlord and tenant are not so

sound. Copernicus also proposed to coin all the money of Prussia at a single mint, forbidding the towns to use their ancient privileges, which had been abused. This proposal, as well as others made in the years 1521–30, failed chiefly because Dantzig and other towns were not willing to relinquish vested rights. It is interesting to note that in his memorial of 1526 he sets the ratio of gold and silver as 1 to 12.

Bishop Fabian died in 1523. During the ensuing vacancy Copernicus was chosen administrator of the diocese. His duties were harassing. The troops of the order encroached more and more on the church holdings. The Lutheran heresy was also a source of anxiety. The steps taken by the administrator were marked by great tolerance. Before the preaching of the new faith was forbidden outright it was enjoined that it should be refuted by argument. A new bishop, Mauritius Ferber, was chosen in 1523, and a word must be said of the bishop's nephew and coadjutor, Tiedemann Giese. Born in 1480, he became canon of Frauenburg about 1504, and was the intimate and affectionate friend of Copernicus during the whole of his life. It was to him that Copernicus confided the manuscript of his great work in 1542. Bishop Ferber died in 1537, and Bishop Dantiscus of Culm was chosen in his place, while Giese by a compromise became bishop of Culm.

The last observation recorded by Copernicus in the 'De Revolutionibus' is dated 1529. From this we may infer that his great work was essentially completed at that time, though it was repeatedly revised afterwards. It had been begun twenty-three years earlier. It was not published until 1543, though its doctrines had been freely communicated to scholars and friends. In 1531 a set of strolling players, set on, it is said, by his enemies among the Teutonic knights and among the Lutherans, gave a little show at Elbing ridiculing the notion that the earth moved round the sun. The play was devised by a certain Dutchman who afterwards became rector of the gymnasium at Elbing. That its satire was understood by the common people proves the opinions of Copernicus to have been fairly well known by his neighbors even at that epoch when absolutely nothing had been printed concerning them. About 1530 a manuscript commentary on the hypotheses of the celestial motions had been prepared by Copernicus for private circulation among men of science in advance of the publication of 'De Revolutionibus.' Two copies of this manuscript still exist, one at Vienna, one at Upsala. At the end of it a *résumé* of his new doctrine is given in seven axioms. (I.) There is only one center to the motions of the heavenly bodies; (II.) this is not the earth about which the moon moves, but (III.) it is the sun; (IV.) the sphere of the fixed stars is indefinitely more distant than the planets; (V.) the diurnal motion of the sun is a consequence of the earth's rotation;

(VI.) the annual motion of the sun and (VII.) the motions of the planets are, primarily, not due to their proper motions.

In 1533 Copernicus was sixty years old and applied for a coadjutor. His duties were, at this time, made light for him. In 1532 an observation of Venus is recorded. Other observations were made in 1537. In 1533 he observed the comet of that year. It may be surmised (his memoir on the comet is not extant) that the retrograde motion of this heavenly body confirmed in his mind his criticisms of the system of Ptolemy.

The theory of Copernicus began to be known in Rome, and it was well received. In 1533 Widmanstad, secretary to Pope Clement VII., gave a formal explanation of the heliocentric theory of Copernicus to the pope and to an audience containing several cardinals and bishops. There is no doubt that the theory was received with interest. There is no sign of opposition, and Widmanstad subsequently obtained high honors in the church. The attitude of the Lutherans was, as we have seen, very different. The cardinal-bishop of Capua wrote in 1536 to Copernicus begging him for an explanation of his system.

In 1537 Dantiscus became bishop of Ermeland. All the canons of Frauenburg, Copernicus included, supported his nomination. Copernicus was known, however, to be a warm friend of Giese, who should have succeeded, as coadjutor, to his uncle's bishopric, but who was elected to that of Culm by a compromise. Difficulties soon arose between Copernicus and his new bishop, and the breach was widened in various ways. The bishop, himself a man of loose morals, ordered Copernicus to send away his housekeeper, on the assumption of illicit relations between the two, and kept the accusation alive by various official letters. Bishop Dantiscus oppressed Copernicus in various ways and remained his enemy in spite of certain advances on the part of the latter. If Copernicus ever feared the persecution of the church on account of his scientific teaching—of which there is little evidence—it was because his bishop stood ready to use every and any weapon against him.

Copernicus gained an ardent disciple in George Joachim of Rhaetia, known to us as Rheticus. He was born in 1514 and made his studies at Nuremberg under Schoner to such effect that he was appointed to be professor of mathematics at the University of Wittenberg in 1537, at the age of twenty-three. In May, 1539, he visited the great astronomer of Frauenburg chiefly to study his doctrines of trigonometry, and his trigonometric tables. Copernicus was then sixty-six years of age and his enthusiastic and loyal guest was twenty-five. He was received cordially and at once set himself to study the manuscripts of Copernicus. His visit extended itself from a few weeks to more than two years, and he

became a firm believer in the new heliocentric astronomy, which he was well prepared to receive and to expound.

A letter from Rheticus, written a few months after his arrival at Frauenburg, affords one of the very few personal views of Copernicus that have come down to us. The letter was published with a long Latin title, in 1540, and is known as 'Narratio Prima.' "I beg you to have this opinion concerning that learned man, my preceptor: that he had been an ardent admirer and follower of Ptolemy; but when he was compelled by phenomena and demonstration, he thought he did well to aim at the same mark at which Ptolemy had aimed, though with a bow and shafts of very different material from his. We must recollect what Ptolemy has said: 'He who is to follow philosophy must be a freeman in mind.'" "My preceptor was very far from rejecting the opinions of ancient philosophers from love of novelty, and except for weighty reasons and irresistible facts. His years, his gravity of character, his excellent learning, his magnanimity and nobleness of spirit are very far from any such temper (of disrespect to the ancients)." This letter, addressed by Rheticus to his old master Schoner, was the first easily accessible account of the new theory. The life-giving sun, he says, is placed in its appropriate place, and a single motion of the earth explains all the planetary motions. All is harmony as if they were bound together with a golden chain. He praises the great simplicity and reasonableness of the new doctrine, as well as the almost divine insight and the uncommon diligence of the master. He had formerly no idea, he says, of the immense labor required in such works, and the example of Copernicus leaves him in astonishment. Copernicus had made a complete collection of all known astronomical observations, and by these his theory was tested. The master was not content until every hypothesis had been fully proved.

Rheticus showed his admiration for Copernicus not only in these public, but also in private, ways. Books that he presented to the master (which are often annotated by Copernicus's own hand) are still to be found in various libraries of Sweden, where they were taken after the plundering of Ermeland in the thirty years' war. At Wittenburg Rheticus and his colleague Reinhold, Copernicans both, were by the conditions of their professorships obliged to teach the Ptolemaic system, just as Galileo, at Padua, a Copernican, had to confine himself to the exposition of Sacrobosco. It may safely be surmised, however, that their pupils did not leave them without hearing something of the true doctrines. In the 'Narratio,' Rheticus, who was a firm believer in astrology, uses the data of the 'De Revolutionibus' as bases for wide-reaching astrological predictions. They are of no interest in themselves, but as the letter was written under the eye of Copernicus, they lead to the conclusion that they were not disapproved by the latter.

So far as I know, this is the only evidence for the belief of Copernicus in astrology. We have no horoscopes from his hand but, like all his contemporaries, he probably gave it a place among the sciences.

Rheticus deserves the gratitude of all calculators for his table of trigonometric functions (sines, tangents, secants) to ten decimal places, for every 10″ of the quadrant, published in a huge volume by his pupil, Otho, under the title 'Opus Palatinum de Triangulis.' The tables of Rheticus are the basis upon which Vlacq founded his great tables, and they have served as models for many followers. Lansberg's tables appeared fifteen years after the 'Opus Palatinum' and lightened the immense labors of Kepler.

Toward the end of the year 1541 Rheticus returned to Wittenberg carrying with him a part of Copernicus's manuscript—a treatise on 'Trigonometry'—which he printed in 1542. The complete manuscript of the 'De Revolutionibus' was sent by Copernicus to his old friend Giese, the bishop of Culm, for such disposition as he thought best. The bishop sent it to Rheticus to arrange for its printing at Nuremberg, and to see it through the press. It fell out that the printing had to be confided to Andreas Osiander, a Lutheran minister interested in astronomy. The book was published early in 1543, and a copy reached Copernicus on May 24, the very day of his death.

Osiander prefixed to the volume an introductory note which he did not sign, as follows:

> Scholars will be surprised by the novelty of the hypothesis proposed in this book, which supposes the earth to be in motion about the sun, itself fixed. But if they will look closer they will see that the author is in no wise to be blamed. The aim of astronomy is to observe the heavenly bodies and to discover the laws of their motions; the veritable causes of the motions it is impossible to assign. It is consequently permissible to imagine causes, arbitrarily, under the sole condition that they should represent, geometrically, the state of the heavens, and it is not necessary that such hypotheses should be true, or even probable. It is sufficient that they should furnish positions that agree with observations. If astronomy admits principles, it is not for the purpose of affirming their truth, but to give a certain basis for calculation.

The best authorities affirm that Osiander's apology, which he had suggested to Copernicus as early as 1540, was unauthorized.

Osiander made many changes in the text also, and added the last two words of the title under which the book was printed—'De Revolutionibus Orbium Cœlestium.' Readers of our day universally interpret the apology to be an attempt to forestall theological opposition and persecution. They remember the conflict of Galileo with the church. But Osiander was a protestant divine, Copernicus a catholic priest. It is passing strange to conceive that a Lutheran schismatic should intervene to shield an orthodox catholic from accusations of heresy. Moreover, Copernicus had good reasons for believing that the princes of the

church would receive his work favorably. His doctrine had been known to them since 1530. He knew, however, that several powerful university teachers—Fracastor for one—opposed it. Ought we not to interpret the apology as an address to men of science? Whewell justly remarks that Copernicus seems to consider the opposition of divines as a 'less formidable danger' than that of astronomers. It is difficult to admit that Osiander dared to prefix this note without the authorization of Copernicus, or, at least, of Rheticus. There seems to be no reason to doubt that it was addressed solely to men of science.

The words of the apology represent the exact point of view of the ancients, and are entirely opposed to the attitude of modern science. Centuries of experience have taught the modern world that there is one and only one solution to a scientific problem. Modern science is a search for such unique solutions. Anything less definite is an hypothesis to be held tentatively and temporarily, it may be even alternatively with another, or others. The theories of the Greek philosophers were, in general, held by them primarily as hypotheses. Their whole attitude towards scientific certainty was thus entirely different from our own. In the time of Copernicus the minds of most men were cast in the ancient temper. It is, in fact, from his century that the new insight dates. This is not to say that colossal geniuses like Archimedes or Roger Bacon did not work in what we call the modern spirit. It is simply to confirm that most of the contemporaries of Copernicus belonged, in this respect, to the ancient world. The apology expressed exactly their attitude. The attitude and temper of the modern world are entirely different; they are perfectly formulated in these words of Pascal: "Ce n'est pas le décret de Rome sur le mouvement de la terre qui prouvera qu'elle demeure en repos; et, si l'on avait des observations constantes qui prouvassent que c'est elle qui tourne, tous les hommes ensembles ne l'empêcheraient pas de tourner, et ne s'empêcheraient pas de tourner avec elle."

It required this very book of Copernicus to suggest the pregnant phrase of Pascal.

In the letter of dedication to the Pope—Paul III.—Copernicus speaks in his own name. His words are simple and serious, full of dignity and conviction:

> I dedicate my book to your Holiness in order that both learned men and the ignorant may see that I do not shrink from judgment and examination. If perchance there be vain babblers who, knowing nothing of mathematics, yet assume the right of judging on account of some place of Scripture perversely twisted to their purpose, and who blame and attack my undertaking, I heed them not and look upon their judgments as rash and contemptible.

He is here referring to divines. The following is addressed to astronomers.

Though I know that the thoughts of a philosopher do not depend on the judgment of the multitude, his study being to seek out truth in all things so far as is permitted by God to human reason, yet when I considered how absurd my doctrine would appear I long hesitated whether I should publish my book, or whether it were not better to follow the example of the Pythagoreans and others who delivered their doctrine only by tradition, and to friends.

The doctrine of Copernicus was first formally judged by the Roman Church in 1615 when Galileo was before the Inquisition in Rome. The judgment was in these terms:

The first proposition, that the sun is the center and does not revolve about the earth, is foolish, absurd, false in theology, and heretical, because expressly contrary to Holy Scripture.

The second proposition, that the earth revolves about the sun and is not the center, is absurd, false in philosophy and, from a theological point of view at least, opposed to the true faith.

In the year 1616 the works of Copernicus were placed upon the Index 'until they should be corrected,' and 'all writings which affirm the motion of the Earth' were condemned at the same time. The congregation issued a notice to its readers in 1620, thus conceived:

Although the writings of Copernicus, the illustrious astronomer, on the revolutions of the world have been declared completely condemnable by the Fathers of the Sacred Congregation of the Index, for the reason that he is not content to announce hypothetically certain principles concerning the situation and motion of the earth, which principles are entirely contrary to the sacred Scripture, and to its true and Catholic interpretation (which can absolutely not be tolerated in a Christian man) but dares to present them as indeed true; nevertheless, because this book contains things very useful to the republic, it has been unanimously agreed that the works of Copernicus ought to be authorized, so far printed, as they previously have been authorized, correcting, however, according to the following notes, the passages in which he does not express himself hypothetically, but affirmatatively maintains the motion of the earth; but those which, in future, will be printed must not be so printed save with the following corrections, which are to be placed before the preface of Copernicus.

The corrections follow; they are not numerous or important.

The works of Copernicus were still on the Index in the year 1819. In the following year Pope Pius VII. approved a decree of the Congregation of the Holy Office that the Copernican system, as established, might be taught, and in 1822 'the printing and publication of works treating of the motion of the earth and the stability of the sun, in accordance with the general opinion of modern astronomers, is permitted at Rome.' Centuries before this date the real question had been judged; but its formal settlement in the Roman Church was postponed to our own day.

The judgments of the Congregation of the Index upon the heliocentric theory were an incident in the history of the relations of Galileo with the authorities at Rome, and they can best be understood in con-

nection with that history. Something, however, may be said of them here. It is to be observed that the first proposition is condemned because it is contrary to scripture, heretical, false in theology, *absurd* and *foolish;* and the second because, from a theological point of view it is opposed to the true faith, *false in philosophy* and *absurd.* The words not in italics relate to judgments upon points of doctrine. The words in italics relate to judgments upon matters of philosophy or of science.

It was entirely competent for the Congregation of the Index to render decisions upon matters of theology which were binding upon all catholics. The committee was organized and existed for that purpose. Every institution, religious or secular, must decide for itself on matters of the sort. Not to do so is sheer suicide. The competence of the Roman church and of the Congregation of the Index to decide *for itself* questions of what is opposed to its faith, contrary to scripture, false in theology, is not to be denied. This was a conflict of theology with an alleged heresy. Copernicus was a member of the Roman Church. The soundness of his theological opinion was a matter for doctors of theology to settle in their own church in their own way. They did not decide it, however, until they had taken the advice of astronomers who pronounced the heliocentric theory to be baseless. (Delambre, 'Astronomie moderne,' i., p. 681.) Tycho Brahé, also—a great authority—had declared it to be 'absurd and contrary to the scriptures.' These two points are often forgotten by writers of the Martyr-of-Science School.

On the other hand, no one can admit for a moment the right or the competence of the Congregation or of the Church to pronounce final judgment upon a question of philosophy or of science. The whole world is now agreed that it is an impertinence for a body of theologians to pronounce upon a question of science, precisely as it would be for a congress of scientific men to pronounce upon a point of theology.

The reasons that led the Congregation of the Index to take this fatal step must be considered in connection with the history of Galileo. It will not be out of place here, however, to attempt to understand the mistaken point of view of the churchmen responsible for the decision.

For fourteen hundred years the theory of Ptolemy had ruled. In 1543 Copernicus proposed a new and revolutionary system. In its essential point the system was true, as we know now; we also know that it was false in asserting that the planets moved in circular orbits (they really move in ellipses), in accepting trepidation as an incident to precession, and in other matters of the sort. It even asserted, falsely, that the center of the orbit of the earth and not the sun was the center of planetary motion, so that in a strict sense it was not even a heliocentric theory. The theory of Copernicus was not

proved to be true, in its essential feature, until Galileo discovered the phases of Venus, in 1610. Is it any wonder that doctors of the church five years afterwards were not convinced? They were profoundly ignorant of science and not in the least interested in science as such. Any one of them could recollect that Tycho Brahé, the greatest astronomer of his time, had in 1587 made a theory of the world which placed the earth at its center. He, then, did not agree with the theory of Copernicus. He expressly rejected it. It could easily be recollected, also, that in 1597 Kepler had proposed his first theory of the world, in which the planets were arranged according to fanciful and false analogies with the shapes of the five regular solids of Plato. It is now known that the systems of Tycho and of Kepler were both false. Ought the church doctors to have accepted them when they were proposed? In 1609 Kepler proposed a second theory of the world based on elliptic and heliocentric motion. How could the doctors know that this second system was the true one, as indeed it was? Kepler was still alive. How could they know that he would not propose a third theory? They had seen the doctrine of Ptolemy denied by Copernicus; the doctrine of Copernicus denied by Tycho; the doctrine of Tycho denied by Kepler's first system; the doctrine of Kepler's first replaced by that of his second system. All this had occurred within their own memories. In scientific theories as such they had no interest whatever; they were solely concerned for religion. Is it surprising that they did not promptly accept a theory which they did not understand?

It was, however, a profound and inexcusable error for them to condemn it; and by so doing they, unwittingly, dealt a heavy blow to the church. For once, theology engaged in a warfare with science; and the issue was an overwhelming and deserved victory for science. There have not been many such conflicts. Very exceptional conditions are required to bring them about, as may be seen in the long history of Galileo.

It is very difficult to form a vivid conception of the whole character of Copernicus either from his works or from his portraits. We know far too little of his history and too little of the time in which he lived. I have found no summary in any of his biographies that can be called satisfying and I have never been able to make one for myself. I venture to reprint that of Bertrand, and to enclose in parentheses those parts that we positively know to need modification or correction.

Capernic est pour nous tout entier dans son livre. Sa vie intime est mal connu. Ce qu'on en sait donne l'idée d'un homme ferme, mais prudent, et d'un caractère parfaitement droit; tout entier à ses spéculations et comme recuelli en lui-même; il aimait la paix, la solitude, et le silence. Simplement et sincèrement pieux, il ne comprit jamais que la verité pût mettre la foi en péril, et se réserva toujours le droit de la chercher et d'y croire. Aucune passion

ne troubla sa vie; (ou ne lui connaît même pas de commerce affectueux et intime*); ennemi des discours inutiles, il ne rechercha ni les éloges ni le bruit de la gloire; indépendant sans orgueil, content de son sort et content de lui-même, il fut grand sans éclat, et, ne se révélant qu'a petit nombre de disciples choisis, il a accompli une revolution dans la science (sans que, se son vivant, l'Europe en ait rien su).†

The system of Copernicus belongs to him alone. It is not the system of Philolaus or of Aristarchus . . . but his own. His name is justly attached to it on account of the care with which he explained its every part, brought out all its phenomena, discovered the causes of these precessional movements which had been known for eighteen hundred years, and explained only by the hypothetical existence of an eighth sphere which made a revolution in 36,000 years around the axis of the ecliptic, while, at the same time, it was constrained to turn daily about the axis of the equator to account for the rising and setting of the stars. It is then Copernicus who really introduced the motion of the earth into astronomy, not merely into academic disputations; it is he who demonstrated how the revolution of the earth about the sun explained the succession of the seasons and the precession of the equinoxes; it is he who showed how simply the retrogradations of the planets are explained by the unequal velocity with which they traverse their concentric orbits about the sun; it is he who put astronomy on new foundations and who opened the way for all later researches. It is to Kepler's enthusiasm over the new truths that we owe the discovery of the true shape of the planetary orbits, and the laws of their motion. The idea of the motion of the earth was unfruitful among the ancients because it was never entertained with seriousness. Its adoption by Copernicus is the beginning of modern astronomy. (Delambre).

The mountain peaks that cluster closely round the Lick Observatory in California are of different heights and were unnamed when the corps of observing astronomers took possession of the newly established station. Names were assigned to them in the order of their heights —Copernicus, Galileo, Kepler, Tycho and Ptolemy. One of the staff of observers, who greatly distinguished himself during his short career at the observatory, objected to the assignment of the name of Copernicus to the highest peak. Copernicus was, no doubt, a great astronomer, he said, but was he preeminent? Should not the highest peak have been assigned to another? The objection is answered the moment the relation of Copernicus to the whole thought of the world is comprehended. His skill as a mere observer, his power as a mere geometer, is not in question. His place is not to be assigned by narrow criteria

* His relations with his uncle and with Giese were both affectionate and intimate; those with the young Rheticus were ideal, considering their ages.

† From the year 1514 onwards his name was widely known among the circles of the learned, and his theories were circulated as early as 1530.

like these. What was the attitude of man towards everything not himself before the day of Copernicus? towards things divine, things spiritual, things natural? What is his view of the world now? The changes are so fundamental, extensive and bewildering as not to be described, much less estimated, except by a long series of separate steps, each one opening new worlds in religion, philosophy, science, art, technics. To name them all would be to summarize the entire history of human progress for three hundred and fifty years. In the long stairway of ascent Copernicus established the foundation stone. Tycho, Kepler, Galileo, Newton, Kant, Laplace, Herschel, Darwin (to speak only of men of science) each laid successive steps upon it. Until the first was firmly laid no building, no advance, was possible. We stand to-day in a high place of vantage won for us by the master builders of more than three centuries. Without Copernicus their work would have been in vain. The modern world is erected upon foundations that he laid.

ON THE SIGNIFICANCE OF CHARACTERISTIC CURVES OF COMPOSITION.

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A FEW months ago, while studying the variation and interrelation of certain sentence constants, as average sentence-lengths, predication averages and simple-sentence frequencies in prose composition, my attention was called to an allied investigation, directed by Dr. T. C. Mendenhall, which takes for its basis the words used by an author rather than the sentences. The investigation in which I was then employed made it clear that the theory which asserts that an author uses invariable average sentence proportions is not true except when modified in essential respects, and I recognized at once that similar modifications would become necessary if the word instead of the sentence were taken as the element of composition.

The allied investigation to which I refer is set forth in two papers by Dr. T. C. Mendenhall, one in *Science*, March 11, 1887, entitled 'The Characteristic Curves of Composition,' the other, 'A Mechanical Solution of a Literary Problem' in THE POPULAR SCIENCE MONTHLY, December, 1901.

These papers deal with the relative frequency of words of different lengths employed by an author. It was found that different groups of a thousand words each, taken from the same author, manifested a rather remarkable uniformity in the frequency of words containing a given number of letters. Larger groups showed still greater uniformity, and hence it was inferred that if sufficiently large groups of words from the same writer were examined, they would yield practically the same relative frequencies of words with a given number of letters.

The results were exhibited graphically. The number of letters per word were used as abscissas, the number of words per thousand containing a definite number of letters were taken for ordinates, and the resulting points connected by straight lines. Thus a graph or diagram was obtained which presents to the eye in a simple manner the relative frequencies of words of different lengths. Two such diagrams from the same author will agree more or less closely, depending upon the number of words in the groups upon which the averages are based. In the writer's own words: "When the number of

words in each group is increased there is, of course, closer agreement of their diagrams, and this became so evident in the earlier stages of the investigation that the conclusion was soon reached that if a diagram be made representing a very large number of words from a given author, it will not differ sensibly from *any other diagram* representing an equally large number of words from the same author. Such a diagram would then reflect the persistent peculiarities of this author in the use of words of different lengths and might be called the characteristic curve of his composition. Curves similarly formed from *anything that he had ever written* could not differ materially from this." (The italics are mine.) After some preliminary work which seemed to bear out the conclusion ventured above, the writer states: "From the examination thus far made I am convinced that 100,000 words will be *necessary* and sufficient to furnish the characteristic curve of a writer—that is to say, if a curve is constructed from 100,000 words of a writer, taken from *any one of his productions*, then a second curve constructed from another 100,000 words would be practically identical with the first—and that this curve would, in general, differ from that formed in the same way from the composition of another writer, to such an extent that one *could always be distinguished* from the other."

Such is the author's own statement of his theory, which the facts adduced apparently support. The culminating test consisted in the examination of different groups of 100,000 or more words from each of several authors, and it was found that the corresponding graphs did actually coincide. This, in the words of the author, 'must be regarded as convincing evidence of the soundness of the original assumption.'

The existence and uniqueness of characteristic curves being granted, its practical application as a test of disputed authorship is obvious. To quote again, "If it can be proved that the characteristic curve exhibited by an analysis of 'David Copperfield' is identical with that of 'Oliver Twist,' of 'Barnaby Rudge,' of 'Great Expectations,' etc., and that it differs sensibly from that of 'Vanity Fair,' or 'Eugene Aran,' or 'Robinson Crusoe,' or 'Don Quixote,' or anything else, in fact, then the conclusion will be tolerably certain that whenever it appears it means Dickens."

The title of Dr. Mendenhall's second paper, 'A Mechanical Solution of a Literary Problem,' refers to the application of this theory to the Bacon-Shakespeare controversy, which, we are told, formed the objective point of the whole investigation. The characteristic curves resulting from 400,000 words of the plays, and 200,000 words from Bacon's 'Henry VII.,' 'Advancement of Learning' and the 'Essays' were constructed and exhibited together as in Fig. 20. The con-

cluding remark that 'the reader is at liberty to draw any conclusion he pleases from this diagram' only strengthens the impression that the conclusion intended is considered unavoidable, though we are told at the outset that 'the investigation is not to be looked upon as a final solution of the principal problem.'

Considering that it is now over fifteen years since the theory of characteristic curves was first outlined and that no denial of it has appeared, it must be taken for granted that the theory has found general acceptance. It is for this reason that I undertook an investigation, which proved laborious and unattractive in the main, in order to combat with facts an error which to me seemed obvious from the outset. The data which I have now at hand, though necessarily meager, are amply sufficient to establish a duality, if not a multiplicity, of characteristic curves for many authors. But this amounts to a denial of Dr. Mendenhall's major premise, and consequently invalidates his conclusion. Fig. 20, instead of furnishing a convincing proof, or even contributary evidence, leaves the problem of disputed authorship wholly untouched. In fact, my results throw considerable doubt upon the very existence of characteristic curves in the sense that the word has been employed by Dr. Mendenhall. I shall, therefore, use the term *word-curve* when referring to curves representing the relative frequencies of different length words used in composition.

Dr. Mendenhall states that the validity of his method as a test of authorship implies two assumptions: first, that the author makes use of a vocabulary which is peculiar to himself, and the character of which does not change from year to year during his productive period; and second, that in the use of that vocabulary in composition, personal peculiarities in the construction of sentences will, in the long run, recur with such regularity that short words, long words and words of medium length will occur with definite relative frequencies.

These two assumptions are of course independent. Suppose it be granted that authors use vocabularies peculiarly their own. It does not at all follow that these peculiarities will manifest themselves in varying word-lengths. Obviously an indefinite number of different vocabularies is conceivable, each yielding the same average word-length or even fitting to the same word-curve. Now, it is true that if authors are endowed with a word-sense or word-instinct by means of which personal traits are reflected through their vocabularies (first assumption), and if, moreover, this word-sense manifests itself in measurable differences in the relative frequencies of words of a given length (second assumption), then these personal traits or peculiarities of an author will in general modify the contour of the word-curve. But the converse of this by no means follows, that the differences in the con-

tours of word-curves are necessarily due to any personal peculiarities in the respective authors.

The average word-length may be reasonably assumed to depend upon other factors besides the author's word-sense, as the form of composition, the subject matter, etc. A man's gait differs according as he is walking for pleasure or on business, alone or in the company of others, on a long journey or to escape from danger. Similarly the average word-length of the language current in the market place, the street or the drawing-room differs from that employed on the rostrum, in learned discourse or in polite conversation, even though used by the same person. Why should not this difference manifest itself in the written utterances of an author?

Dr. Mendenhall, by an enormous expenditure of labor, attempts to prove his second assumption. How? By taking for granted the converse of the very proposition which he wishes to establish. He actually constructs the word-curves for Mill, Jonson, Dickens, Bacon, Shakespeare and finding that they differ in contour, attributes these differences to personal peculiarities of the respective authors. Not once seems the question to have been raised, much less answered, whether these differences are not due wholly or in part to other determining conditions, such as the form of composition or other accidents.

Now not only can it be shown that the form of composition, at least, is a modifying factor of the word-curve and average word-length, but it appears, indeed, to be the predominating factor, overshadowing all others. Works agreeing in form of composition, though written by different authors, will be found to yield curves more nearly in agreement than different works of widely divergent forms of composition by the same author. Whether or not the author-component in the word-curve can be separated from the others is unknown; certain it is that nothing of the kind has as yet been attempted. With our present knowledge concerning word-curves, conclusions regarding the authorship of spurious or disputed writings based upon a comparison of the word-curves of works differing either in the form of composition or in other essential respects must be considered worthless.

It is not difficult to predict in a general way in what respects word-curves of different types of composition will differ. In the vernacular of a language, so nearly devoid of inflection as our English, three- and four-letter words will naturally predominate. The development of oral speech, following the path of least resistance, will naturally be from the simple to the complex. Combinations of five, six or more letters, representing as many elements of sound, will not generally be resorted to so long as there are abundant simpler combinations, consistent with the possibilities of vocal articulation, to draw from. Now while the possible combinations of two and three letters into words is

inadequate for a civilized language, the possible number of two-, three- and four-letter words, aggregating thousands, is sufficient to supply the majority of words needed for every-day speech. The word-curve of common conversation may therefore be expected to show a maximum ordinate for three or four letters. Words containing five, six or more letters will occur with diminishing frequencies. Few words of more than ten letters will occur. Now this is exactly what takes place. Swift's 'Polite Conversation,' which is a reproduction of the conversation of the uncultured, yields the word-curve shown in Fig. 1. This, after a correction for an excess of seven- and eight-letter words, due to the frequent occurrence of the words ladyship, lordship and certain proper names, is the typical word-curve of extreme light dialogue.

What now will be the probable variations as we pass from this extreme type of composition to other forms of dramatic prose? As conversation becomes more sustained the relative frequency of the personal pronoun 'I' will naturally diminish, the use of prepositional phrases will cause two-letter words to increase, words of six and seven letters will become more numerous at the expense of the frequency of three- and four-letter words. The resulting word-curve must, therefore, cross the former in two places, once between the abscissas one and two, and again near the abscissa five. If we pass from the heavier forms of dramatic prose to narrative, in which dialogue alternates with description and still heavier composition, the personal pronoun will diminish still more in frequency, two-letter words will continue to increase as will also words of six, seven and more letters, and to compensate for this there must be a further decrease in the relative number of three- and four-letter words. This law of change will continue as we pass from fiction to pure description and from the essay style to the opposite extreme of scientific and philosophic discourse. Here the personal pronoun 'I' will have disappeared, leaving the indefinite article 'a' the practically sole representative of one-letter words; with the accumulation of phrases and clauses there is a corresponding accumulation of two-letter prepositions, three- and four-letter words will have reached a minimum to make room for longer derivatives, compounds and technical terms.

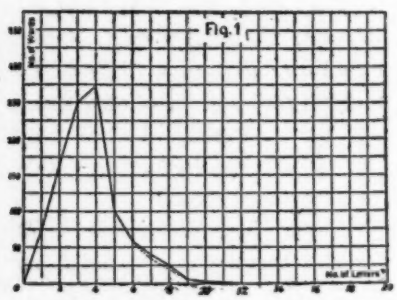

FIG. 1. 5,000 WORD-CURVES FROM SWIFT'S 'POLITE CONVERSATION.' Corrected curve.

Throughout these changes the five-letter word will probably vary least, since the variations on opposite sides of it are in contrary directions. We assume it constant. Taking furthermore Swift's 'Polite

Conversation' and Mill's 'Political Economy' as representatives of the opposite extremes of the chain of forms of composition just described, we have the following schematic types of word-curves (Fig. 2) characteristic not of any particular author, but of the form of composition employed.

Of course no one would expect anything more than an approximate conformation to these types in any specific case, for we have already stated that the form of composition into which an author casts his

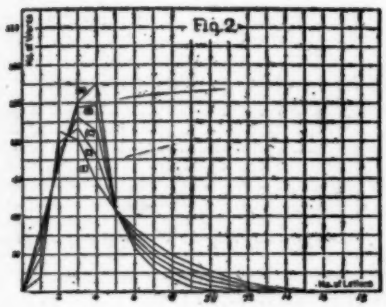

FIG. 2. SCHEMATIC WORD-CURVES REPRESENTING, (*A*) 'Light Conversation,' (*B*) Classic Dramatic Prose, (*C*) Fiction, (*D*) Essay and Description, (*E*) Scientific and Philosophic Discourse.

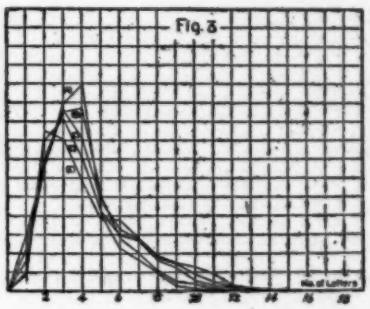

FIG. 3. ACTUAL WORD-CURVES, (*A*) Swift's 'Polite Conversation,' (*B*) Beaumont and Fletcher's Dramatic Works, (*C*) Dickens's 'Christmas Carol,' (*D*) Bacon's 'Essays' and 'New Atlantis' and 'Henry VII.,' (*E*) Mill's 'Political Economy.'

thought is but one of several possible factors affecting the word-curve. But Dr. Mendenhall's diagrams seem to show that it is the predominating factor. In Fig. 3 I have superimposed on one the other four of Mendenhall's diagrams, and to complete the series I have added the word-curve of Swift's 'Polite Conversation.' A more striking corroboration of our hypothesis could scarcely be expected from data intended to establish the theory of characteristic curves.

It may be pointed out in passing that our hypothesis explains several puzzling phenomena brought out in Dr. Mendenhall's investigations. It is now clear why none of the thousand word-graphs from Dickens's 'Oliver Twist' 'could by any possibility be mistaken' for any one of ten similar graphs from Mill's 'Political Economy,' why the 10,000 word-curve from Mill's 'Political Economy' varies very strikingly from a similar curve from his 'Essay on Liberty' (Fig. 4). It explains why the two word-curves of 10,000 words each, one from 'Oliver Twist,' the other from 'Vanity Fair,' agree so closely, fully as closely in fact as two different curves of 10,000 words each from Dickens himself (Fig. 5), an occurrence which Mendenhall remarked, 'must be largely the result of accident, and it would not be likely to repeat itself in another analysis.' Finally our hypothesis removes all

cause for surprise that Shaler's 'Armada Days,' composed 'in the spirit and style of the Elizabethan Age,' should yield a word-curve resembling that of Shakespeare's plays.

Seeing that the assumption that word-curves vary according to the composition employed accounts for nearly everything which had been attributed to personal characteristics of the authors, and that it also explains so much which is inexplicable on the opposite assumption, I

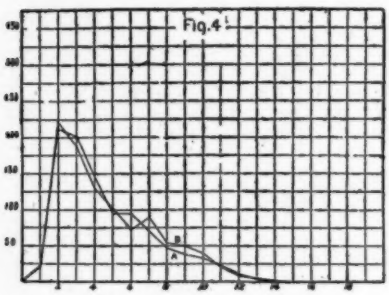

FIG. 4. TWO 5,000 WORD-CURVES (AFTER MENDENHALL) FROM JOHN STUART MILL. (*A*) 'Political Economy,' (*B*) 'Essay on Liberty.'

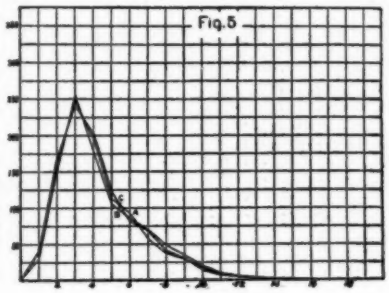

FIG. 5. THREE 10,000 WORD-CURVES OF FICTION (AFTER MENDENHALL). (*A*) Dickens's 'Oliver Twist,' (*B*) Thackeray's 'Vanity Fair,' (*C*) Dickens's 'Christmas Carol.'

sought for a way to test it. But how? According to Dr. Mendenhall, 'no one has written enough in two or three different styles, as prose, poetry, history, essay, drama, etc., to produce normal characteristic diagrams.' This, if true, would exclude any positive test of our hypothesis, but a moment's reflection convinced me that the assumption is entirely unwarranted. Goethe has among his prose works alone, volumes each of drama, biography, fiction, travel, science, criticism and correspondence. Schiller, too, has written far to exceed 100,000 words each of prose, drama and history. And what about Voltaire with his seven volumes of drama, eleven of history, seven of essays, ten of philosophy and eighteen of correspondence, besides several others of poetry, romance, science and commentaries; or George Sand or Lamartine with their libraries of books written in various forms of composition? Our own Dryden, also, has written of essays and prose dramas each more than sufficient to furnish a normal word-curve from each.

Here then was sufficient material to demonstrate the truth or falsity of our hypothesis, if only means could be found to carry out the work. Dr. Mendenhall convinced himself that no less than 100,000 words are necessary to yield an invariable curve, and it would evidently require several such curves to furnish any safe ground for induction. But the examination of several hundred thousand words, allowing but two hours for the tabulation and classification per thousand, would require a greater sacrifice of time than other duties would

permit me to make. Indeed, Dr. Mendenhall found himself in the same predicament, from which he was rescued by the generosity of a private citizen, who supplied the salaries of two assistants for several months during which the necessary data were collected.

Then it occurred to me that though one hundred thousand words may be necessary to yield an invariable curve, a much smaller number might suffice to establish the existence of such a curve within certain limits. If these limits for the curves of different forms of composition from the same author turn out to be mutually exclusive, our hypothesis would be established, though we had not examined a sufficiently large number of words to determine the locus of the curves with accuracy. Thus, possibly, the work necessary to test our hypothesis might reduce itself to manageable proportions.

The first author examined was Goethe. To eliminate as far as possible the disturbing effect of unconscious bias, I decided to count in word-groups of consecutive thousands, always beginning with the first of the work. Quotations, footnotes, headings and, in the case of dramas, stage-directions, etc., were uniformly omitted. These rules were strictly adhered to in all the data which follow. Five groups of one thousand words each were taken from each of Goethe's 'Bürgergeneral,' and 'Literatur Recensionen,' (*B*). The results were tabulated as follows:

TABLE I.

Goethe: 'Bürgergeneral.'

No. of Letters.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Av.
No. of words, 1st 1,000	0	88	331	217	146	91	44	38	19	13	4	5	2	1	1					4.385
" " " 2d "	0	107	326	172	166	79	32	54	24	25	6	2	1	3	1	2				4.498
" " " 3d "	1	91	319	197	136	95	59	32	26	15	12	7	7	1	1		1			4.485
" " " 4th "	1	73	338	204	142	85	53	32	25	16	11	8	3	3	5		1			4.509
" " " 5th "	7	87	324	172	158	93	51	39	22	18	11	4	8	3	1	1	1			4.599
Average 5,000 words.	2	89	328	192	150	89	48	39	23	19	9	5	4	2	2	1	1			4.513

Goethe: 'Literatur Recensionen' (*B*).

No. of Letters.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Av.
No. of words, 1st 1,000		51	268	113	105	122	92	53	65	36	41	21	14	8	5		2	4		5.802
" " " 2d "		48	262	111	131	115	70	66	73	43	32	20	7	11	4	3	1	7		5.792
" " " 3d "		69	261	107	124	112	76	84	61	43	24	17	7	5	7	1	1	1		5.610
" " " 4th "		72	250	109	93	141	87	59	62	57	27	19	10	6	3	3	2			5.716
" " " 5th "		61	251	127	118	111	89	65	67	33	34	10	16	4	2	10	1	1		5.698
Average 5,000 words.		60	258	113	114	120	83	65	66	42	32	17	11	7	4	3	1	3		5.723

Each thousand words was now plotted separately and the resulting two sets of five curves compared (Fig. 6 and Fig. 7). These results far exceeded my expectation. No curve of the one set could possibly be mistaken for any curve of the other set. Three-letter words, of which there were between 319 and 338 in each thousand of the first set, were reduced to 250 to 268 per thousand in the second set;

nine-letter words, which did not exceed 26 in any thousand of one, rose to 73 in the other. A similar contrast prevailed in the relative frequencies of four-, seven-, eight- and ten-letter words in the two sets of data. In this case then, at least, five thousand words seemed

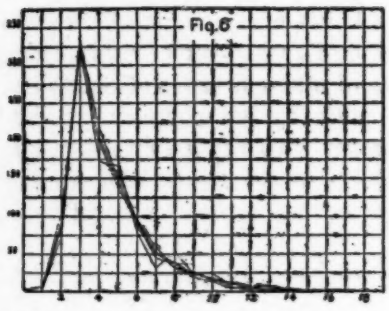

FIG. 6. FIVE 1,000 WORD-CURVES FROM GOETHE'S 'DER BÜRGERGENERAL.' (See Table I.)

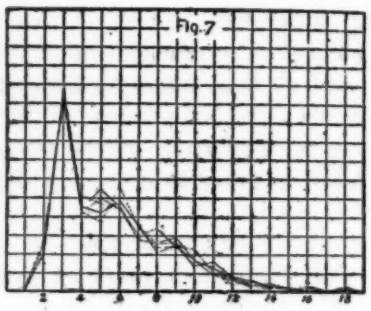

FIG. 7. FIVE 1,000 WORD-CURVES FROM GOETHE'S 'LITERATUR: RECENSIONEN.' (See Table I.)

sufficient to indicate the limits of the invariable curves which a larger number of words would yield, and these limits are actually exclusive except in the proximity of the intersection of the two sets of curves. The normal curve for each group of five thousand words is given in Fig. 8.

Goethe may possibly be exceptional in manifesting such striking uniformity in the curves for successive thousands of the same work, and an equally striking divergence in any two curves belonging to different works. So I turned to Schiller. Ten thousand words were examined, five thousand from his '*Kabale und Liebe,*' a prose drama, and five thousand from his 'History of the Thirty Years' War.'

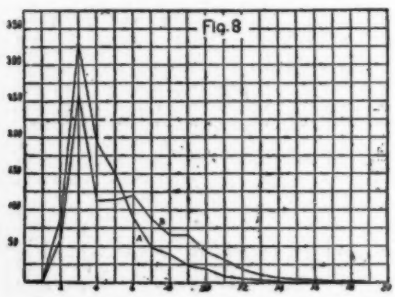

FIG. 8. TWO 5,000 WORD-CURVES FROM GOETHE. (Table I.) (*A*) Prose Drama ('Der Bürgergeneral'), (*B*) Criticism ('Literatur: Recensionen').

A glance at the corresponding word-curves for each thousand words (Figs. 9 and 10) shows that here, too, five thousand words will determine the limits within which the unknown invariable word-curves will be confined with a sufficient definiteness to convince us that the curves can in no wise resemble each other. Four-letter words occur only about half as frequently in the 'History' as in the 'Play'; ten-, eleven-, twelve-letter and longer words are increased two and three-fold.

TABLE II.

Schiller: 'Kabale und Liebe.'

No. of Letters.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	+	Av.
No. of words, 1st 1,000		78	298	203	148	96	54	28	36	19	15	9	7	7	2						4.784
" " " 2d "	2	93	268	209	139	119	55	30	41	14	15	8	2	1	2		1		1		4.738
" " " 3d "	2	82	294	178	139	134	56	47	26	17	14	6	1	2	2						4.978
" " " 4th "		94	277	188	128	107	49	48	37	21	21	10	4	5	1	1	1				4.924
" " " 5th "	2	82	252	195	143	122	55	48	39	18	15	12	8	4	3	1		1			4.291
Average 5,000 words.	1	86	278	195	137	116	54	40	36	19	16	9	4	4	2						4.833

Schiller: 'History of the Thirty Years' War.'

No. of Letters.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	+	Av.
No. of words, 1st 1,000		87	246	103	135	133	65	48	43	32	49	19	13	5	7	6	2		3	2	5.712
" " " 2d "		65	259	96	109	127	86	48	44	51	49	28	11	8	5	5	6	1	1	1	5.937
" " " 3d "		79	256	100	140	86	68	68	63	27	31	27	16	14	7	5	2	8	2		5.878
" " " 4th "		76	256	131	116	115	62	56	41	34	46	23	10	11	6	9	5	2	1		5.745
" " " 5th "		85	232	106	125	117	63	62	53	39	33	34	17	5	9	10	6	2	1	1	5.957
Average 5,000 words.		78	250	107	125	116	69	56	49	37	42	26	13	9	7	7	4	3	1	1	5.846

Fig. 11 gives the word-curves constructed from five thousand averages of the two works.

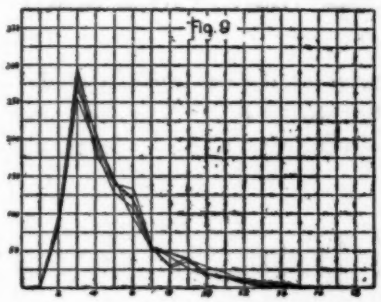

FIG. 9. FIVE 1,000 WORD-CURVES FROM SCHILLER'S 'KABALE UND LIEBE.' (See Table II.)

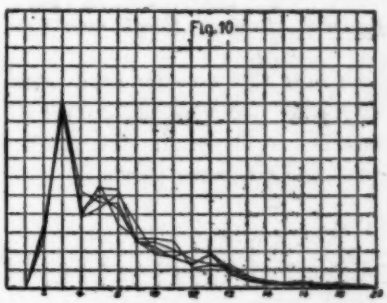

FIG. 10. FIVE 1,000 WORD-CURVES FROM SCHILLER'S 'THIRTY YEARS' WAR.' (See Table II.)

Next I tabulated ten thousand words from Goldsmith, choosing the drama 'She Stoops to Conquer' and his essay on the 'Present State of Polite Learning in Europe.'

TABLE III.

Goldsmith: 'She Stoops to Conquer.'

No. of Letters.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Av.
No. of words, 1st 1,000	76	175	245	185	106	78	57	32	18	14	9	1	3		1	4.021
" " " 2d "	74	216	207	186	96	54	68	44	25	18	6	3	1	1	1	4.032
" " " 3d "	51	197	250	208	89	62	54	27	34	13	10	2	3			4.047
" " " 4th "	64	201	215	220	108	49	67	30	20	14	6	3	2		1	3.997
" " " 5th "	65	217	208	184	92	78	67	37	21	15	9	4	3			4.073
Average 5,000 words.	66	201	225	197	98	64	63	34	24	15	8	3	2		1	4.046

Goldsmith: 'Present State of Polite Learning in Europe.'

No. of Letters.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Av.
No. of words, 1st 1,000	19	231	193	102	87	77	90	74	48	45	25	7	1	1		4.854
" " " 2d "	12	174	207	145	102	94	70	49	53	40	31	18	3	2		5.018
" " " 3d "	16	175	199	148	112	76	62	79	52	42	20	8	10	1		4.985
" " " 4th "	34	183	208	134	116	64	70	55	66	31	18	14	3	4		4.819
" " " 5th "	20	184	178	146	142	95	77	61	39	27	16	10	3	2		4.797
Average 5,000 words.	20	189	197	135	112	81	74	64	52	37	22	11	4	2		4.895

Here the results, graphically exhibited in Figs. 12, 13 and 14 are somewhat less satisfactory than in the case of Schiller or Goethe, yet

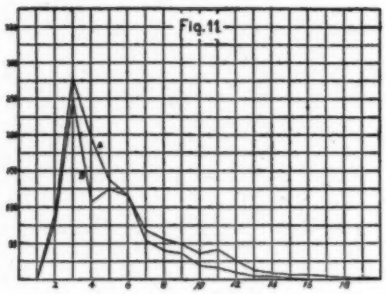

FIG. 11. TWO 5,000 WORD-CURVES FROM SCHILLER. (Table II.) (*A*) Prose Drama 'Kabale und Liebe,' (*B*) History 'Thirty Years' War.'

even here any one-thousand word-curve of the one work is easily distinguished from all the curves of the other work. The most marked contrast is shown in the relative frequencies of two-, four-, eight-, nine- and ten-letter words.

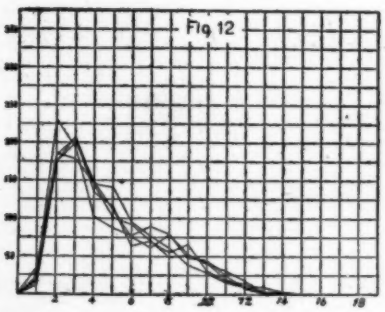

FIG. 12. FIVE 1,000 WORD-CURVES FROM GOLDSMITH'S 'SHE STOOPS TO CONQUER.' (See Table III.)

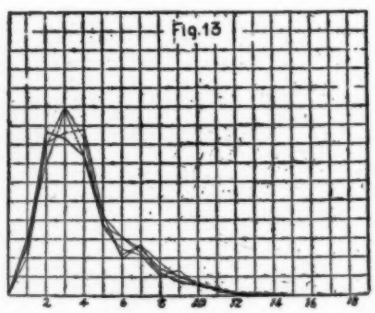

FIG. 13. FIVE 1,000 WORD-CURVES FROM GOLDSMITH'S 'PRESENT STATE OF POLITE LEARNING IN EUROPE.' (See Table III.)

On the other hand, Dryden's one-thousand word-curves (Fig. 15 and Fig. 16) appear fully as differentiated as any yet examined. Five thousand words each from 'Sir Martin Mar-all' and the 'Essay on Satire' give:

TABLE IV.

Dryden: 'Sir Martin Mar-all.'

No. of Letters.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Av.
No. of words, 1st 1,000	46	176	263	236	101	69	37	36	25	7	2	1		1		3.940
" " " 2d "	55	181	275	202	98	59	46	33	21	13	8	9				3.995
" " " 3d "	71	189	260	220	114	60	39	28	9	8		1			1	3.724
" " " 4th "	56	174	272	238	104	62	45	25	11	9	3	1				3.813
" " " 5th "	70	184	241	231	93	64	56	31	12	10	6	1			1	3.875
Average 5,000 words.	60	181	262	225	102	63	45	31	16	9	4	3				3.869

Dryden: 'Essay on Satire.'

No. of Letters.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Av.
No. of words, 1st 1,000	30	187	242	184	96	62	72	50	39	17	14	4	1	1	1	4.387
" " " 2d "	36	199	224	186	94	76	75	35	24	25	13	7	3	1	1	4.352
" " " 3d "	38	200	210	183	107	76	71	49	26	22	10	4	2	2		4.346
" " " 4th "	23	192	225	160	111	99	80	56	24	16	5	7	1	1		4.421
" " " 5th "	27	196	228	172	103	90	69	54	26	20	10	1	1	2	1	4.371
Average 5,000 words.	31	195	226	177	102	81	73	49	28	20	10	5	2	1	1	4.375

Here not only are five thousand words sufficient to indicate that the invariable curves for the two kinds of writing differ essentially, but the number of four-letter words alone in any single thousand seems to characterize the drama from the essay.

It seemed hardly necessary to augment these data which may seem to the reader more than adequate to establish the multiplicity of the so-called characteristic curves of an author. Still I ventured another test. Suppose several five-thousand word-curves from different dramatic works of an author were constructed, and again several five-thousand word-curves of various other prose productions as criticism or history by the same author. Suppose it were found that each set of curves agrees in the main, but differ, in essential respects, from all the curves of the other set, could this be interpreted otherwise than that the nature of the composition is the determining factor of the curves? With this thought in mind, I tabulated four additional groups of five thousand words each from Goethe, two groups each taken from single works, the other two groups made up of single thousands from each of ten different productions. These together with the five thousand averages previously obtained from the 'Bürger-general' and 'Literatur Recensionen' (B), are given in Table V., and the corresponding word-curves are given in Fig. 18. Fig. 19 shows the two curves which result if the entire fifteen thousand words are taken

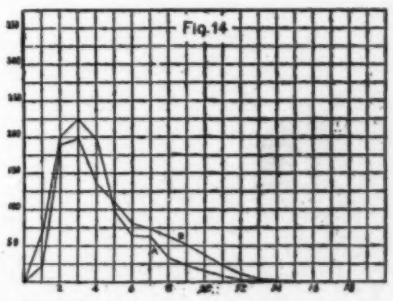

FIG. 14. TWO 5,000 WORD-CURVES FROM GOLDSMITH. (Table III.) (*A*) Drama 'She Stoops to Conquer,' (*B*) Essay 'Present State of Polite Learning in Europe.'

TABLE V.

Goethe: 'Prose Drama.'

No. of Letters.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	+	Av.
Egmont, 1,000 words.		68	318	201	149	107	47	51	17	20	8	6	2	2	2	2			4.647
Clavigo, " "	1	79	295	202	140	115	48	35	29	25	14	10	1	3		2		1	4.761
Stella, " "	1	86	285	202	140	119	58	46	25	14	12	8	2	2					4.685
T. d. Empfindsamkeit, 1,000 words.	3	78	300	175	143	110	57	52	30	28	14	2	3	2	2				4.780
Die Aufgeregten, 1,000 words.	1	67	325	184	158	101	55	39	23	18	17	4	5	2					4.605
Average, 5,000 words.	1	74	305	193	146	110	53	45	25	21	13	6	3	2	1	1	1		4.706
Gaetz v. B., " "	1	84	315	193	138	113	53	36	25	16	11	8	4	3	1	1	1		4.626
Der Bürgergeneral, 5,000 words.	2	89	328	192	150	89	48	39	23	19	9	5	4	2	2	1	1		4.513
Average, 15,000 words.	1	83	316	193	145	104	51	40	24	19	11	6	4	2	1	1	1		4.616

Goethe: 'Criticism and Description.'

No. of Letters.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	+	Av.
St. Rochus Fest, 1,000 words.		56	267	112	128	108	68	69	61	52	30	24	10	11	1	2		1	5.716
Im Rheingau, " "		58	257	118	122	120	72	49	53	40	38	26	16	14	4	5	5	3	5.877
Köln, " "		80	232	100	91	118	84	70	57	59	44	36	16	8	4	1			5.982
Campagne in F., " "		65	268	110	124	99	63	93	43	40	34	23	15	11	4	5			5.720
It. Reise: Rom, " "		78	266	135	148	110	60	49	42	38	30	23	12	5	2	1	1		5.359
Average, 5,000 words.		67	258	115	123	111	70	66	51	46	35	26	14	10	3	3	1		5.731
Laokoon, Propyläen, " "		70	271	135	113	114	70	68	50	37	29	17	11	7	3	2	2		5.505
Literatur R. (B), " "		60	258	113	114	120	85	65	66	43	32	17	11	7	4	3	1	3	5.727
Average, 15,000 words.		69	262	121	117	115	74	67	56	42	32	20	11	8	4	3	1	1	5.654

as the basis. These will approximately coincide with the invariable curves for the two kinds of composition in question.

Throughout our work we have used the word-curve as the basis of comparison. But the mere fact of divergence of such curves for different forms of composition could have been much more readily estab-

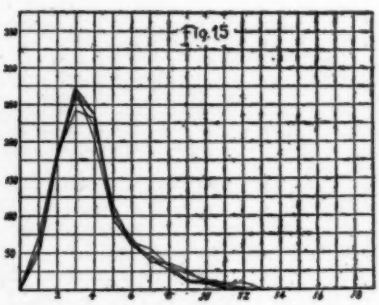

FIG. 15. FIVE 1,000 WORD-CURVES FROM DRYDEN'S 'SIR MARTIN MAR-ALL.' (See Table IV.

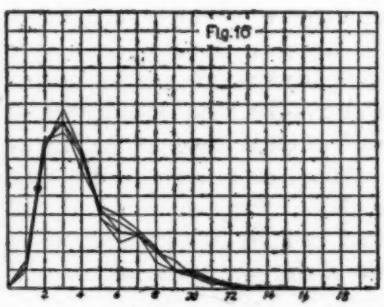

FIG. 16. FIVE 1,000 WORD-CURVES FROM DRYDEN'S 'ESSAY ON SATIRE.' (See Table IV.)

lished by an inspection of the average word-lengths of various works. It will pay to compare carefully the numbers given in the last columns of our tables. None of the averages per thousand in Goethe's prose dramas *exceeds* 4.8 letters per word; in none of his other works examined do the averages *fall below* 5.4. The limits of the average word-lengths for the two forms of composition are thus seen to be not only

exclusive, but they are separated by a wide gap. Goldsmith's averages, 4.0 and 4.9 letters per word, respectively, show a similar difference, and so do Schiller's and Dryden's averages. Doubtless this factor of average word-length alone, which can be determined with an expenditure of but a small fraction of the time required for the de-

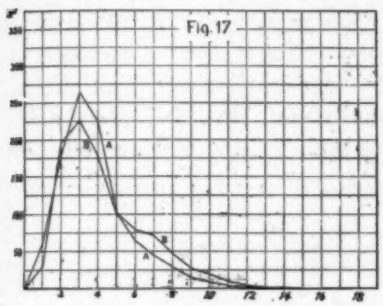

FIG. 17. TWO 5,000 WORD-CURVES FROM DRYDEN. (Table IV.) (*A*) Prose Drama 'Sir Martin Mar-all,' (*B*) Essay 'Essay on Satire.'

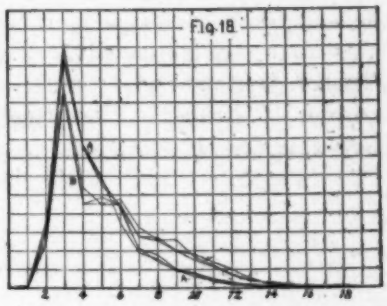

FIG. 18. SIX 5,000 WORD-CURVES FROM DIFFERENT WORKS OF GOETHE. (See Table V.) (*A*) Three dramatic prose curves, (*B*) Three curves of criticism and description.

termination of the figures necessary to construct the word-curves, would in general be indicative of the nature of the curve, so that in critical cases only, the word-curve would need to be examined.

The question still remains whether two word-curves of the same author may vary as much as the word-curves of different authors, that

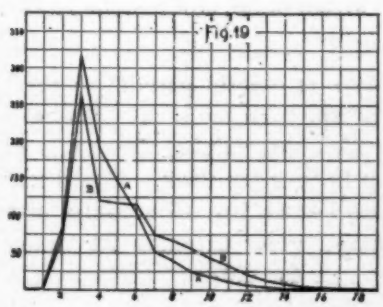

FIG. 19. TWO 15,000 WORD-CURVES FROM GOETHE. (Table V.) (*A*) Dramatic prose, (*B*) Criticism and description.

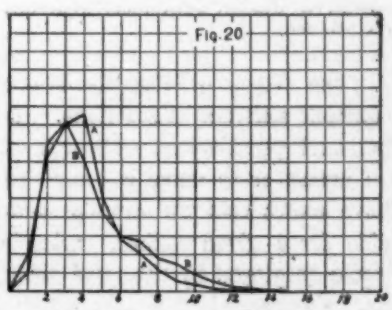

FIG. 20. (*A*) 400,000 Word-curve from Shakespeare; (*B*) 200,000 Word-curve from Bacon. (After Mendenhall.)

is, whether, so far as word-curves indicate anything, an author differs as much from himself as from other authors. This question can not be definitely answered until a large number of authors have been compared, that is, until we have obtained the maximum variation between authors, as well as the maximum variation between various forms of composition. But so far as the evidence at hand may be

trusted, it is to the effect that the line of demarcation follows the form of composition rather than the author. Figs. 11, 14, 17 and 19 show variations that must be attributed to the form of composition; the difference in the curves of Fig. 20 may reasonably be ascribed to the same cause. Fig. 21 shows four five-thousand word-curves, representing two authors and two styles of writing. The curves representing the same style not the same author follow each other. Fig. 22 contains four words-curves of dramas (Shakespeare, Beaumont and Fletcher, Marlowe and Jonson), and four word-curves from the prose writings of Bacon, Dryden, Goldsmith and Mill. While the latter show considerable variations among each other, they are all clearly differentiated from each of the drama curves.

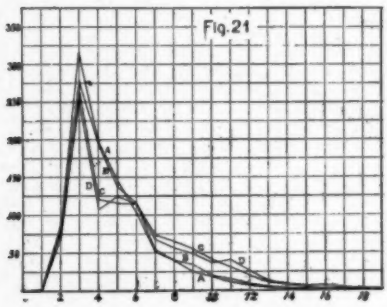

FIG. 21. TWO CURVES EACH OF DRAMATIC PROSE AND DESCRIPTIVE PROSE FROM DIFFERENT AUTHORS. Dramatic Prose, (*A*) Goethe, (*B*) Schiller; Description, (*C*) Goethe, (*D*) Schiller.

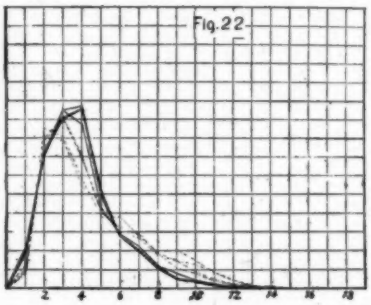

FIG. 22. EIGHT WORD-CURVES FROM ENGLISH WORKS; Dramas (Shakespeare, Beaumont and Fletcher, Marlowe, Jonson), Prose Writings (Bacon, Dryden, Goldsmith, Mill).

The theory of characteristic curves is exactly parallel to that of constant sentence proportions. Both rest upon the same fallacy—that personal peculiarities outweigh all other determining factors to such an extent as to make it unnecessary to consider them. Elsewhere* I have shown that the average sentence length, instead of being invariable for a given author, varies between wider extremes for different styles employed by the same author than for different authors writing in the same style. Goethe alone shows average sentence lengths varying from 5 to 38 words per sentence. Is it not likewise probable that a more extended inquiry would reveal, in the case of versatile writers like Goethe, Voltaire and others, not two only, but a whole series of invariable word-curves, distributed something like the curves in Fig. 2?

It was the theory of spectrum analysis which first suggested to Dr.

*The Sherman principle in rhetoric and its restrictions. POPULAR SCIENCE MONTHLY, October, 1903. On the variation and functional relation of certain sentence constants in standard literature, University (of Nebraska) Studies, July, 1903.

Mendenhall the analogous conception of word-spectra or characteristic curves. Just as the light-rays of various wave-lengths emitted by a substance combine to form its spectrum, so a combination of words of various lengths in proper definite ratios make up an author's word-spectrum or characteristic curve. The analogy is imperfect, but we admit it. But is it true that each substance has a single spectrum? This was the supposition when the science of spectrum analysis was in its infancy, and upon this supposition Dr. Mendenhall bases his analogy. The fact is that over forty years ago it was demonstrated that some substances have several spectra, and to-day it is generally believed that all substances have several spectra, corresponding to the several stages of disassociation or molecular composition of their molecules. The analogy to spectrum analysis, therefore, demands the modification of the theory of characteristic curves, which I have tried to point out in the preceding pages.

THE PHYSIOGRAPHIC CONTROL OF THE CHATTANOOGA CAMPAIGNS OF THE CIVIL WAR.

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CORNELL UNIVERSITY.

AT the opening of the civil war, the leaders of both sides clearly recognized three regions around which important campaigns must center. The confederacy was at a disadvantage in having no marked natural boundaries. The rivers and mountain led *into* rather than *around it*. The territory of the seceding states was roughly divided into three physiographic sections, each of which required a separate force. East of the Appalachians were the Piedmont and coastal plain regions, the struggle for which centered in the vicinity of Richmond. On the west was the Mississippi Valley, the 'gateway to the confederacy.'

The middle section included the rugged portions of Kentucky and Tennessee. By a singular combination of surface features the key to all this area lay in the comparatively small region in the vicinity of Chattanooga. It is the purpose of this paper to trace the relations between the campaigns centering about Chattanooga to the topography of the region—their 'earth control,' as the geographers would say.

"Chattanooga," says Fiske, "was the northern gateway to the center of the confederacy. From it radiated railroads to the Ohio, Mississippi, Gulf and Atlantic; through it were the railroad connections of Virginia with the southwest. Its possession by the federal army would isolate Virginia and North Carolina from the western states of the confederacy, and open a way through Georgia to Atlanta and thence to the coast." On the other hand, its control by the confederates gave them the fertile valleys of east Tennessee and allowed them to threaten Kentucky and western Tennessee. They could readily move troops and supplies between the army in Virginia and the forces in the west. The mountaineers in Kentucky and Tennessee were largely unionists and this provided an additional strong incentive for the federals to control the region.

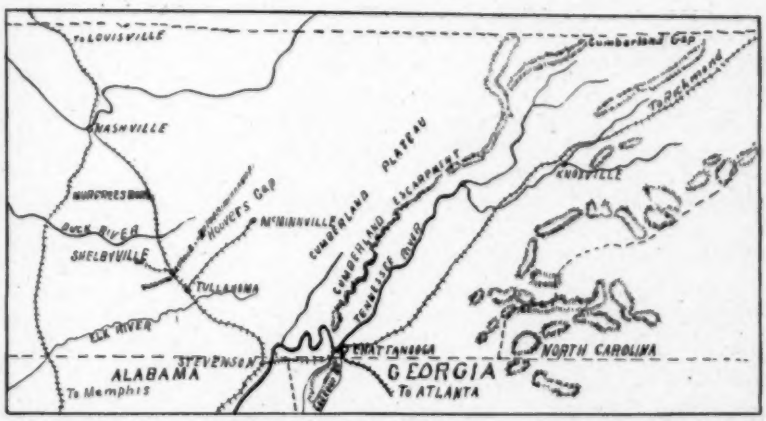
The importance of Chattanooga during the war and the cause of its industrial development since are largely due to physiographic and geological influences. Within a space of a few miles three different geological structures, each having a characteristic physiographic development, approach each other.

Taking these regions in order, the first to the eastward is the Appalachian. It is an apparent jumble of peaks, ranges and valleys, as a glance at the relief map will show. Their ancient crystalline rocks

have weathered with comparative slowness, and consequently the mass stands out in strong relief, extending nearly to the Atlantic and most effectively separating the southern Atlantic seaboard from the interior. So effective a barrier were they that communication from the coastal plain with northern Georgia, Tennessee and Kentucky was either by the passes in Virginia or around the southern end of the mountains by way of Atlanta. Prior to 1880 there was no railroad across these mountains south of Roanoke.

Some of the intermontane valleys are fertile and support a considerable population, but the general inaccessibility of the region is shown by the life and customs of the people, which have scarcely changed since revolutionary times.

In the tilting and folding incident to the formation of the Appalachian system, there was exposed a belt of limestones and shales extend-



OUTLINE MAP OF THE REGION INCLUDED IN THE CHATTANOOGA CAMPAIGNS.

ing in a direction roughly parallel to the mountain axis. These rocks are tilted and their upturned edges are easily eroded as compared with those on either side. The result of this erosion is an irregular trough from ten to seventy-five miles wide and over a thousand miles long. It is known in general as the 'Great' or Appalachian valley, but has various local names. In New Jersey it is known as the Kittatinny valley; in Pennsylvania it is the Cumberland valley; in Virginia it becomes the Shenandoah valley and in this region, the Tennessee valley or the East Tennessee valley.

The rocks are much inclined and their parallel edges of different degrees of resistance are exposed to the process of denudation, the results of which are long, narrow, parallel ridges running lengthwise along the valley. For example, the famous Chickamauga Ridge is composed of a compact resistant rock, known as Knox dolomite, which stands above the valley floor because the neighboring strata are less resistant to the levelling effects of denudation. The traveler going

through the region is not likely to recognize the valley form, as most of the roads are in smaller valleys between the ridges, but once gain some commanding elevation and the great valley is seen stretching away, its ridges and hills melting into insignificance on its apparently level bottom. The decomposed rock makes a fertile soil which early attracted settlers. From New York to Alabama it is the abode of a prosperous people with well tilled farms and comfortable homes.

Extending westward from the valley is a plateau region which merges on the north and west into the Mississippi valley and is known

RELIEF MAP OF THE CHATTANOOGA DISTRICT. (Photographed from model by E. E. Howell.)

as the Cumberland Plateau. The geologist finds no difficulty in accounting for the transition from valley to plateau when the rock arrangement is seen. Here instead of the highly tilted strata of the valley, the rock layers are nearly horizontal. Instead of the troughs and ridges of the valley, the surface, while rough, has an even sky line which tells of a former approximately level surface. The elevations are steep and the streams seem to have no regular arrangement—in short, this region is a 'dissected' plateau. The surface stratum of rock in general is a sandstone which is underlaid by a stratum of more easily soluble limestone. When a stream has cut through the sandstone layer and reaches the limestone, it deepens its valley more rapidly than before and consequently flows in a steep trench.

The overlying sandstone protects the limestone beneath and prevents

its active weathering, thus the rate of recession of a cliff is entirely regulated by the recession of the overcapping stratum. The general result upon the topography is high, cliff-like valley walls, and rather level-topped hills with steep slopes. Where the plateau meets the great valley, this is shown on a grand scale. From Chattanooga northeastward along Walden's ridge for scores of miles stretches a cliff or escarpment which overlooks the valley. It is steep and the streams flowing across the escarpment have gashed it into a serrate profile which gives it the local name of Cumberland Mountain. The lack of roads and general inaccessibility of plateau and escarpment made it a factor to

GENERAL VIEW SHOWING ONE OF THE APPALACHIAN VALLEY RIDGES IN MONROE COUNTY, TENN. (Photographed by the U. S. Bureau of Forestry.)

be reckoned with in the movement of armies. The plateau is heavily timbered and, in contrast with the valley, is difficult of access and sparsely settled. The relief map of the Chattanooga district shows the surface appearance of these divisions.

The drainage of these regions is as peculiar and characteristic as are the surface features. The great valley is a structural valley, and not, as are most valleys, the seat of a great river. Its existence, as has before been noted, is due not to river activity, but to the easy denudation of its rocks as compared with those on either side. The only large

rivers flowing lengthwise of the valley are the Shenandoah and Tennessee. These and the smaller streams have a general direction parallel to the valley trend. They have discovered strata which they can erode and into which they have sunk their channels. The streams on the plateau have no such succeeding parallel strata to guide their course and have cut valleys in an irregular fashion, not unlike the branching of a tree.

Looking at the course of the Tennessee, it would seem that the river could hardly have taken a more roundabout way to the sea. Rising about seventy miles above Chattanooga, it follows the valley trend until it reaches this place. There, instead of continuing about three hundred miles down the valley to the Gulf, the river turns abruptly to the westward and enters the plateau by a deep gorge. Flowing in a meandering course, it passes through northern Alabama and across Tennessee and Kentucky, entering the Ohio River at Paducah, over fifty miles north of its source. It finally reaches the Gulf after a circuitous journey of more than three times the distance that would be required had it taken the course down the valley. Indeed, it is thought that the Tennessee at one time did follow the shorter course, but a tilting of the land together with the rapid erosion eastward of a westward-flowing stream, diverted the river to its present course.

The civil war opened with the Chattanooga region in the hands of the confederates who also controlled Tennessee and Kentucky to the north and west. Both sides were fully alive to the importance of the position and for over two years it was the objective of the union armies. But at this time Chattanooga was nearly one hundred miles within the confederate lines, which reached from Columbus, a strongly fortified post on the Mississippi, to Cumberland Gap, at the northeast corner of Tennessee, where there was a pass to the Great Valley. At about the center of the line were forts Donelson and Henry, which commanded respectively the Cumberland and Tennessee rivers. These rivers were natural roadways into the confederacy, and it was an important step when Grant captured the forts. The first advance toward Chattanooga had been taken, and from now on until its capture Chattanooga was the goal of some union army in Tennessee.

General Rosecrans was in command of the army which found itself ready to start for Chattanooga, with General Bragg as his opponent. Bragg had attempted an invasion of Kentucky, but was checked at the battle of Stone River near Murfreesboro, which left the two armies facing each other on the Cumberland plateau. Rosecrans's army and supplies were concentrated at Murfreesboro and Bragg had his center resting at Tullahoma, a straggling village important only as a railroad junction. The Tullahoma campaign which now followed was indecisive, but is interesting to the student of military history because of the strategy by which Rosecrans forced his adversary to retreat without

incurring serious loss to the federal army. Its consideration is also appropriate in this article, since the plans of the commanders and the movements of their forces were very largely controlled by the physiography of the plateau.

So deeply dissected is this plateau that, without exception, military writers speak of it as the Cumberland 'Mountains.' Weathering and stream work, continued through untold ages, have cut deep valleys and carved hills until we have the present rough country to cross which, even without an enemy in front, was no small undertaking. The soil, derived from Carboniferous sandstone in general is a thin sandy loam,

VIEW IN THE DISSECTED CUMBERLAND PLATEAU, NEAR SEWANEE, TENN. The Mountains are formed by denudation, leaving an even sky-line. (Photographed by the U. S. Bureau of Forestry.)

and only in the valley bottoms where the streams have worn a trench and partly filled it with alluvial sediment is the soil fairly fertile.

The plateau descends towards the plains of middle Tennessee by three great irregular terraces each roughly about five hundred feet high. Through these terraces streams have carved narrow valleys through which the roads pass to the lowlands. These gorges, called 'gaps' by the mountaineers, were as important to the armies in that section as were the 'wind gaps' between Virginia and the Shenandoah valley to the confederates. They were easy to hold with a small force against a numerous body of the enemy and were especially serviceable to a retreating army, since a small rear guard was able to give complete protection.

The question of railroad transportation was an almost paramount one in these campaigns and, as we have seen, was one of the reasons for the military importance of Chattanooga. The modern army with its concentration of men and horses is rarely able to live on the country through which it passes, especially if it is on an offensive campaign and traversing territory through which the enemy has passed. To do so would involve the spreading of the troops over a large area or detaching a considerable force to forage. Sherman's famous march to the sea was a successful instance of a large army living on the country, but he had no active enemy in his front and was passing through the 'garden of the confederacy.' If a railroad or river is not available for transporting supplies, resort must be had to wagon trains.

The average army wagon was drawn by six mules and carried a day's rations for five hundred men. If the distance were such that the wagon could not make a complete trip in one day, more wagons were required. It was even harder to provide food for the horses. When cattle could be driven it would give some relief to the wagon trains. To give a general idea of the magnitude of this work, it is estimated that it required one thousand wagons and six thousand horses to feed an army of fifty thousand men when they left the railroad or base of supplies for a distance of two days' march. This estimate assumes good roads and no breakdowns or stoppages by the enemy and does not include transporting the sick and wounded or the ammunition and materials of war.

The Louisville and Nashville railroad winds through the plateau following the valleys which the streams have cut. It crosses many streams and deep gorges by wooden bridges which were easy to destroy and difficult to rebuild. Both armies were dependent on this road for their supplies. About Tullahoma the soil, before it was cleared, supported a growth of pines and from the general inhospitality of the region was known as the 'Pine Barrens.' The soil drainage was so easy that in a dry summer there was scarcity of water on the uplands, but in a rain, as one of the federal officers complains, 'The soil became as quicksand after a rain, allowing artillery and wagons to sink to the hub.' Thus the dependence of the two armies upon the same line of railroad was almost absolute.

After the battle of Murfreesboro, Bragg's policy was one of defense. His position was strong and well taken. His center and depot of supplies was at Tullahoma, where he had thrown up extensive intrenchments. His left was at Shelbyville, about thirty miles to the northwest in the Duck River valley. This town was in a fairly fertile alluvial valley which offered some sustenance for the troops and horses and, further, was a center from which roads diverged in all directions. Moreover, if he were forced from his position, he could retreat to the plateau which could be fairly easily defended. To his right from Tul-

lahoma, Bragg had posted bodies of troops for the double purpose of defense and of threatening the union base at Murfreesboro. Bragg believed that he had sufficient men in this vicinity to guard the narrow defiles through which most of the roads ran.

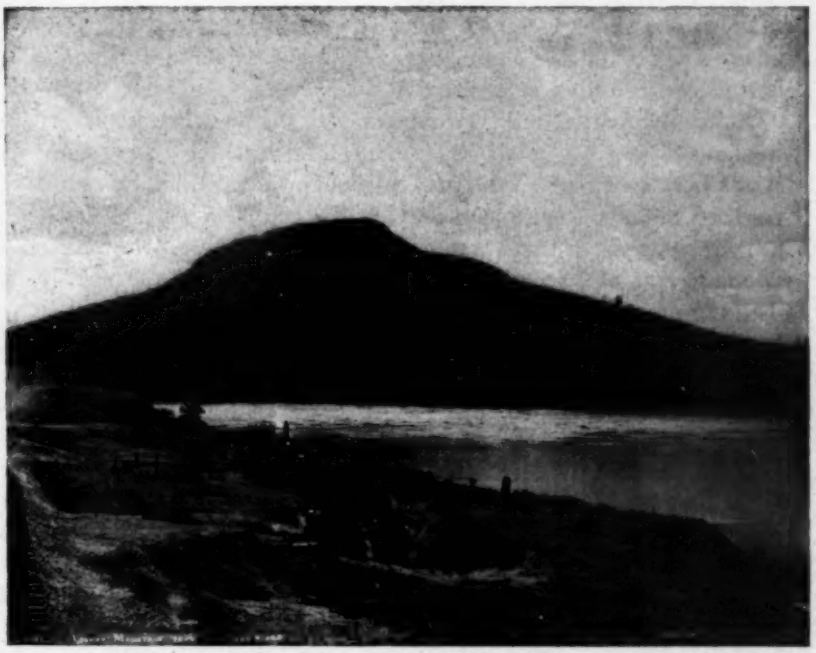
Without going into detailed accounts of movements of troops, Rosecrans's plan may be briefly stated. Realizing the strength of Bragg's left at Shelbyville, the union general resolved to attempt what his opponent evidently considered well-nigh impossible—to get his forces on Bragg's right in such a position as to threaten the latter's line of communication and compel him to evacuate his strong position.

THE TENNESSEE BREAKING BY A STEEP GORGE THROUGH THE 'MOUNTAINS.' Owing to the swift current it is there called the 'Suck.'

A strong union force with several days' rations in wagons and *on hoof* was detached for this movement. A vigorous attack on Bragg's left partly concealed the plan of Rosecrans and prevented him from sending reinforcements from here. The movement was successful and the defiles or 'gaps' were secured by which the troops could pass to the level of the plateau on which Tullahoma was situated. The confederate general, not waiting for his line of supplies to be destroyed, retired to the Tennessee, burning the bridges and destroying the railroad as he went. A pursuit was attempted which was entirely ineffectual. The passage of the confederate army had left the roads almost impassable and their rear guard had little trouble in defending the defiles through which their columns had passed. Bragg crossed the Tennessee and leisurely led his army into Chattanooga.

MOCCASIN BEND FROM LOOKOUT MOUNTAIN. Chattanooga is seen in the middle ground. The long even sky-line to the left is the plateau escarpment. The small plateau on which the battle of Lookout Mountain occurred is in the immediate foreground.

At this stage the immediate topography of Chattanooga and its vicinity became important in determining the military movements. Looking at the relief map it will be seen that the city lies at the western side of the great valley close to where the river breaks into the plateau. It winds through Sand Mountain in a deep gorge which narrows in places, making the current so swift that an ordinary steamboat could not ascend without aid from teams or men on the shore. When the river reaches a long, narrow trough, called the Sequatchie valley, it takes this easier path and flows sixty miles before again crossing the plateau in its indirect course to the Ohio. Near the city the river flows to Lookout Mountain and then doubles on itself, flowing northwesterly,



LOOKOUT MOUNTAIN FROM THE BANK OF THE TENNESSEE RIVER. Hooker's forces ascended the north slope and the battle took place on a small plateau or shelf, seen about half way up the mountain.

almost parallel to its course, for several miles. This is the famous Moccasin bend, so called, of course, from its rough resemblance to an Indian's moccasin. At the apex of the bend towers Lookout Mountain, the most conspicuous feature of the vicinity. Geologically it is a part of the plateau from which it is separated by a narrow erosion valley. It is capped by a sandstone stratum which slopes to the south, where it finally merges into the general level in Alabama. Its bold profile against the sky at once attracts the eye, and the name is decidedly appropriate, since on a clear day several states can be seen from the summit. The ridge, for so it must be called instead of 'mountain,'

rises in slopes so steep that they were insurmountable by an army, until its summit is fourteen hundred feet above the rapid current. A mile or so eastward is Missionary Ridge, roughly parallel to Lookout, but much lower and more accessible. Its top is really a succession of hills or knobs. Between these ridges is Chattanooga Creek, which enters the Tennessee near Chattanooga. Still to the eastward of Missionary Ridge is the famous Chickamauga Creek. Looking westward from Lookout summit, the view is wild and picturesque in the extreme. Extending to the base of the mountain the valley of Lookout Creek is seen in the immediate foreground. Beyond that is the rough Sand Mountain, whose name tells the story of its rock structure and suggests its scraggly covering of trees and shrubs. To the northwest the river winds in its narrow gorge in the plateau for a few miles and disappears around Sand Mountain. North of the river Sand Mountain is continued and known as Walden's Ridge.

Returning to the military movements, we find Rosecrans on the Cumberland plateau, in the vicinity of McMinnville. For some time he was busy repairing the seventy miles of railroad leading from Murfreesboro towards Chattanooga, which the confederates had destroyed in their movement southward. Some of the bridges of this road were destroyed and rebuilt four times in the course of the war. The Chattanooga and Nashville railroad passed to Stevenson, a small town about thirty miles down the river from Chattanooga, where it joined the railroad leading from Chattanooga to Memphis on the Mississippi. Stevenson was the federal base of supplies. The road then crosses the river at Bridgeport, crosses through a ravine, a spur of Sand Mountain into Lookout Valley, and thence passes around the northern end of Lookout Mountain into Chattanooga. To protect this line Rosecrans was obliged to detail thousands of his troops; each bridge was guarded by a detachment of soldiers who generally had built a stockade in the vicinity. The country was swarming with detached bands of hostile 'guerrillas' who would wreck a train or burn a bridge and then escape.

The union commander had open to him two approaches to Chattanooga. He could advance over Walden's Ridge directly upon the city, but this route was beset with difficulties. The roads were very poor and led over the hilly, wooded plateau. After a rain they speedily became impassable to wagons. His base of supplies and nearest railroad point was at Stevenson, from which he would be compelled to haul supplies for the army in the presence of an enemy well supplied with cavalry; moreover, he would have to cross the river in boats at Chattanooga in the face of a vigilant foe. In spite of its difficulties this was the way which Rosecrans was generally expected to take, as it was thought that Burnside, who was near Knoxville, up the valley, would come down and join in the movement.

The other approach lay along the river valley and across Sand Mountain. The advantage of this route was that the army was near its base of supplies, with which it had both river and railroad connection. However, the roads were poor and the route lay across parallel ridges, almost inaccessible except in a few places. It would be hard to maintain a compact advance over the rough country, and a regiment of the enemy could easily delay an army. Rosecrans chose this route and the manner in which he maneuvered his army was certainly a brilliant piece of strategy.

Bragg had expected the federal army to come over Walden's Ridge, and Rosecrans did all in his power to strengthen that belief. Troops were deployed in front of Chattanooga and at night camp fires were lighted on the hills above the river. By feinting in this way Rosecrans was able to advance his army into Lookout Valley without encountering opposition. From here he went through the passes of Lookout Mountain into Chattanooga Valley and threatened Bragg's line of communication with the south. Bragg led his army out and, after a series of maneuvers, the battle of Chickamauga was fought with disastrous results to the federals. Had it not been for the stand made by Thomas, the 'Rock of Chickamauga,' the union army would have been routed. As it was, they were driven into Chattanooga and imprisoned by a seemingly impregnable line of works. Lookout Mountain was abandoned and at once occupied by the confederates. It was apparently the key to the situation.

Rosecrans had caught the wolf by the ears. He had gained Chattanooga, but was a prisoner in its outworks. To advance against the strongly entrenched enemy was folly. To retreat across the plateau would have demoralized his army besides losing the position he had won at such cost. Worst of all, the enemy had taken possession of Lookout Mountain, which Rosecrans had felt obliged to abandon. They had fortified the position and placed guns which commanded the river and railroad west of Chattanooga, thus cutting off supplies from that direction. For awhile provisions came over the Cumberland plateau, but the hardships of the route soon exhausted the teams which could not follow the river, as that was patrolled by the enemy's pickets and were obliged to take circuitous roads over the hills and away from the river. The cattle that were driven that way were hardly able to stand alone, much less furnish sustenance. The soldiers with grim humor spoke of them as 'dried beef on the hoof.' Bragg, confident of his game, sat down and waited for the union army to be starved into surrendering, and his hopes did not seem unreasonable.

The north was thoroughly alarmed at this state of affairs and Grant was put in command. His first work was to open a line by which supplies could reach the city. The celerity with which he accomplished this makes one wonder why it was not done before. The only feasible

route was up the river, but the works on Lookout Mountain controlled both the river and the railroad west of the town. Down the river and out of range of the guns on Lookout was Brown's ferry, which was guarded by a force of confederates. Hooker's division, which had been brought from the east, was thrown across the river and, capturing the force there, entrenched a position commanding the river, which was now clear below this point.

The famine in Chattanooga soon ended. Supplies came to Bridgeport, from thence to Brown's ferry, which Hooker was guarding, and then by wagon to the army. The soldiers were soon well fed and clothed by the 'cracker route,' as it was appropriately called.

Grant was now free to develop offensive plans. It will be remembered that Bragg's lines stretched from his left on Lookout Mountain to Missionary Ridge, where his right was strongly entrenched; Thomas was to threaten the confederate center, Sherman was to attack heavily on Missionary Ridge and Hooker was to move on Lookout Mountain and the enemy's left.

The latter's movement in the celebrated 'battle above the clouds' was successful. However, since the establishment of the new line of supplies, Lookout had ceased to be the key to the position. Sherman found the opposing works stronger than he expected and he was not immediately successful. However, in the center the unexpected happened. This position was believed to be too strong to be carried by direct assault and the attack was intended to prevent reinforcements being sent against Sherman. The troops had orders to stop at the first rifle pits, but they could not be restrained. They rushed up the steep slope, carried the position and the confederate center was broken. Bragg was badly beaten and withdrew to Dalton. The region was not out of union hands during the rest of the war.

Chattanooga's importance has not ceased with the close of the war. Its position at the gateway between the grain and cotton states, together with the resources of the surrounding country, makes the location of an important city in this region almost inevitable. Since the war, the river has been made navigable most of the year to the Ohio. Railroads have multiplied and eleven lines enter the city. Iron, coal, limestone, cotton, lumber, grain are near at hand in the valley and plateau. The city's population and manufactories have doubled in a few years. The battlefields in the vicinity have been surveyed and mapped and the Chattanooga and Chickamauga parks rank with Gettysburg among the military parks of the world.

At a point near Chattanooga one can view the two aspects of the place without changing his position. In the beautiful national cemetery rest over twelve thousand veterans of '63. Turning a little, the city is in view. Its factories are a prophecy not only of the city, but as well of the New South.

THE VALUE OF TEETH AS A MEANS OF IDENTIFICATION.

BY ALTON HOWARD THOMPSON, D.D.S.,

PROFESSOR OF COMPARATIVE ODONTOGRAPHY, KANSAS CITY DENTAL COLLEGE.

I HAVE been reminded by the articles in the POPULAR SCIENCE MONTHLY, of the neglect of the teeth as a means of identification, which to me, as a practical dentist, has always seemed very remarkable. No system of identification that I am aware of has ever mentioned these valuable organs for this purpose, notwithstanding the facts that they are so varied in features and are so durable. They are the most indestructible of all animal tissues and their value in this respect ought to be appreciated, for after death, when all the other tissues have disappeared, the teeth remain and maintain the features and peculiarities that they presented in life. It is a source of wonder to the dental profession that the signs furnished by the teeth have been so persistently overlooked in systems of identification, especially by life-insurance companies. The number of signs furnished by the teeth, both of natural features and of artificial operations upon them, is so varied and extensive that they present an amount of valuable data that ought not to be ignored.

A simple system of record of the natural peculiarities of the teeth and of the artificial operations upon them could be devised which in the hands of a competent person, who would need to be an expert dentist, of course, would furnish reliable and less perishable evidence than the other external signs of the body. Every dentist keeps a record of all the operations he performs for every patient, upon an individual chart or page in a special diagram, for his own convenience and protection. By means of these charts, dentists have, in several instances, assisted materially in the identification of the bodies of persons for whom they have operated, after catastrophes, notably the charity bazaar fire in Paris. A similar chart could be incorporated in the examination records of life insurance companies, for instance, on which the dental peculiarities could be recorded in a manner which could be easily read by another expert. Even if some teeth were lost or altered in the course of years, many signs would yet remain on the surviving teeth, for the original form of a tooth would be the same and an artificial operation could not be obliterated. Thus the size and width of the arch; the size, shape and color of the teeth; teeth missing

or altered; kind of fillings and location; gold crowns, bridges or artificial plates, etc. All these and other distinct features could be easily recorded with sufficient clearness to enable the record to be compared with the subject, even if dead and if only the skeleton remained, to assist materially in identification by another expert.

By way of suggesting a scheme for the tabulating of the dental peculiarities, the following plan of classification is proposed, which covers all the general features of the teeth and their environments and could be recorded by one and read by another expert dentist. This scheme is merely suggestive and could be improved by practise and experience.

Classified list of dental and oral peculiarities:

(*a*) Curve of arch, whether round, square or V-shape.

(*b*) Width of arch, in centimeters—from outside surfaces of first upper molars.

(*c*) Depth of vault, from grinding faces of molars.

(*d*) Color and texture of gums, peculiarities of ridges in roof.

(*e*) Size of teeth, whether large small or medium.

(*f*) Shape of teeth, whether wide or narrow, long or short, worn or not, etc.

(*g*) Color of teeth, white or dark, yellowish, bluish or modifications, etc. (This factor would be modified by time and habits, but the expert observer would estimate that.)

(*h*) Irregularities of the teeth, as to being out of normal place, crowding and malpositions generally.

(*i*) Teeth absent totally.

(*j*) Fillings in teeth—noting positions on crown and materials employed.

(*k*) Cavities of decay unfilled.

(*l*) Diseased teeth, dead teeth, chronic abscess, etc.

(*m*) Artificial teeth crowns—porcelain, gold, bridge teeth, etc.

(*n*) Artificial teeth on plates.

(*o*) Miscellaneous peculiarities—such as abrasion, pits or other congenital markings; lingual cingules; number of cusps on second lower bicuspids, upper second molars, etc.; third molars, whether present or absent; forms of crowns, etc., and all abnormal forms of teeth, etc.

Many of these characteristics might be perishable, of course, and of value only for a limited time, but others are of permanent durability and would last while the teeth themselves lasted. The perishable data would need to be taken into consideration at a later examination and a practical dentist would naturally make such allowances. The absence of some data would not always mean lack of identity, for a reasonable allowance would need to be made for perishable dental features.

A chart is shown as an example on which is recorded some of the peculiarities of an ordinary mouth according to this scheme. (Fig. 1) (*a*) Round square. (*b*) 5.8 cm. (*c*) 2.5 cm. (*d*) Gum reddish-pink; health line well marked; rugæ shallow and rather straight. (*e*) Medium small. (*f*) Rather wide and short, cusps low and rounded.

(*g*) Rich cream color shading to yellowish at cervical border. (*h*) Upper laterals both everted at mesial border: right lower central crowded inward. (*i*) First right upper bicuspid and second left lower molar missing; first upper molar broken off and roots remaining. (*j*) 1, gold filling; 2, large amalgam filling; 3, cement filling. (*k*) 1, deep decay; 2, shallow decay. (*l*) Dead tooth and chronic abscess and fistula. (*m*) 1, gold teeth crown; 2, porcelain crown. (*n*) 1, third molar peg-shaped; 2, both lower bicuspids of tricuspid form; 3, whitish spot on labial face.

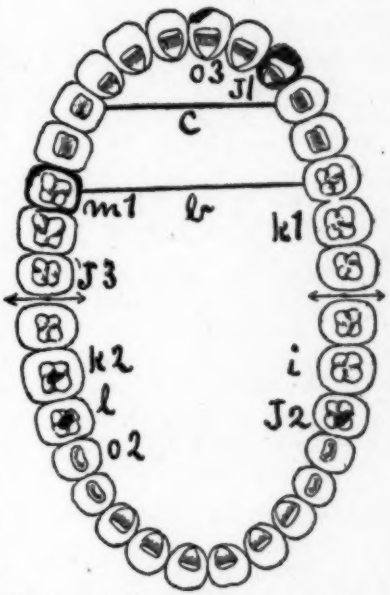


FIG. 1. UPPER JAW ABOVE; LOWER JAW BELOW.

The history of life insurance litigation demonstrates the value of imperishable physical data for the purpose of identification, and these data the teeth furnish. It is more than probable that much expensive litigation and unfair decisions would have been avoided if these data had been heretofore utilized. In the celebrated Hillmon case, which dragged its slow length for twenty years through the United States courts of the west, casts of the alleged corpse of Hillmon were placed in evidence which showed that the denture was perfect and regular, while the teeth of Hillmon himself were said to be irregular and some were absent. It was a case in which the body was so disfigured by decomposition that evidence in regard to the teeth was of the utmost importance. If a chart of Hillmon's own teeth could have been produced which showed some of his dental peculiarities (missing teeth, irregularities, fillings, etc.) a comparison with the teeth of the corpse would have been of advantage so that the case would have been sooner settled and much tedious and expensive litigation avoided.

The data are so accessible and so important, that we feel justified in urging the matter upon the attention of those who have charge of the classes of which physical records are required. The dental data should be employed as supplementary to other systems of signs for identification, and would thus be of value in the records of soldiers and criminals as well as for insurance companies.

IMMIGRATION.*

By Dr. ALLAN McLAUGHLIN,
U. S. PUBLIC HEALTH AND MARINE HOSPITAL SERVICE.

CAUSES of emigration may be considered according to their origin, and divided into three classes. (1) Individual—the spontaneous desires for better things arising in the emigrant himself; (2) local—existing conditions surrounding him in his old world home which develop and stimulate his inherent desire for social, political or financial betterment; (3) extraneous—outside influences operating from America or other countries.

In considering the causes arising within the emigrant himself—the desire for ownership of a home will be found present in a very large proportion of cases. This desire for his own home probably exists in the heart of every man worthy of the name. It forms the foundation of our social structure and is the unit of civilization and advancement among all progressive races. In the early days of the republic it is certain that the immigrant was a homeseeker in nearly every instance, like his predecessor the colonist. And probably this desire to become owners actuates the majority of immigrants, even in our own day.

Often coupled with the desire for ownership of a home there exists in the independent liberty-loving immigrant a desire for free institutions, for a country where the schools are open to all regardless of race or creed, where he may worship God in his own way, according to the faith of his fathers, and where in time he may through the franchise play at least a small part in the political life of his adopted country.

The emigrant leaves often to escape compulsory military service in support of a government in which he has little or no representation. Thousands of European immigrants who arrived in the United States just previous to or during the civil war left Europe rather than submit to compulsory military service, and yet voluntarily enlisted and served faithfully in the union armies in the great conflict. They showed that they were not afraid to fight when the cause at issue was in accord with their principles, but that they resented the military system of their native land.

* Dr. Allan McLaughlin, of the Bureau of Public Health and Marine Hospital Service, of the Treasury Department, has contributed to THE POPULAR SCIENCE MONTHLY several articles on 'Immigration,' which have been of much interest to readers and have been highly commended by experts. We are pleased to state that Dr. McLaughlin has consented to continue this series of articles, covering in a systematic way the whole problem of immigration.—EDITOR.

And then there is the restless emigrant who desires simply to better his financial condition. He recognizes no patriotic obligation to the new country which treats him kindly, and has no quarrel with the country of his birth, but intends returning to his native land when he has acquired a competence in the United States.

Many of the existing conditions in Europe act strongly as contributing causes of emigration—the price of land in many countries is prohibitive, especially when the poverty of the mass of the people is considered. In other countries, systems of land tenure obtain which make it impossible for the tenant to become an owner.

In parts of Europe discrimination against certain races or religions is carried to the extent of debarring any one of the proscribed race or religion from owning land. This same discrimination against race or religion imposes educational barriers in some countries which prevent the elevation of the poor because of their race or religion in the social scale.

Many emigrants, therefore, leave Europe because they know that in the United States their children will enjoy educational advantages denied them at home, and without which they can not hope to better their condition.

Great density of population and the accompanying excessive competition in the struggle for existence explain emigration from some parts of Europe, and emigration is further stimulated in many of these congested areas by the pressure of militarism.

When some of the contributing causes originating in Europe are accentuated, when militarism exists with its concomitant evils of grinding taxation and compulsory military service, when persecution and over-crowding make the struggle for existence hopeless, emigration becomes the alternative of starvation, and the instinct of self-preservation forces these unfortunate creatures to flee at the first opportunity to some new country.

Convicts, paupers, cripples and diseased persons have many times been shipped to America 'to be rid of them,' by individuals, societies, municipal corporations or even by government agents.

Of the third class of extraneous causes operating from America or other countries, the most important is the prosperity of the United States.

During periods of great prosperity the wave of immigration attains its greatest height, and reaches its lowest ebb during periods of industrial and commercial depression. Thus during 1882 and 1903, the total of our immigration reached its maximum, while following 1873 and 1893 a rapid falling off is noticeable. The people in Europe are informed of our wonderful industrial growth and general prosperity by letters from friends and relatives in this country. These letters contrast conditions of life in America with the poverty or oppression of the

old world, and often contain considerable sums of money, which is convincing evidence to the European peasant. During periods of depression the tone of the letters reflects the change of circumstances and letters are less likely to contain cash remittances. According to statements of steamship officials, from 40 to 55 per cent. of our immigrants come here on tickets prepaid by friends in the United States—so that the successful immigrant here is the best advertisement of the advantages afforded by the United States, and one of the greatest factors in inducing immigration.

There is no doubt that in the past large employers of labor encouraged emigration from Europe, but there is no longer any necessity for them to induce emigration, either by agents or by advertisement, and the practise has almost ceased.

The transatlantic steamship companies have found the business of transporting immigrants to America very profitable and have done much to develop our immigration to its present mammoth proportions. Although the steamship companies deny the fact, a well organized system undoubtedly exists in Europe, by means of which agents and sub-agents of the steamship companies induce emigration. The companies do not openly countenance the system of misrepresentation which the sub-agents employ, but the fact remains that it is in their power to remedy this evil, which they still permit to be practised. For the sake of the commission allowed them these sub-agents picture America as an El Dorado to the peasants, telling them that passage to America is the certain road to fortune.

One of the most potent causes of emigration from Europe is the assistance given the poor of certain races by rich individuals or philanthropic associations. Thousands of Roumanian and Russian Jews, forced by persecution to emigrate, are assisted by the Jewish societies or individuals in the towns through which they pass and are thus helped to the seaboard. Many are passed on through Hamburg, Rotterdam, Libau or some other continental port to London. Here they are met by the representative of the 'Hebrew Shelter.' This institution was founded in 1885, for providing a temporary refuge, and to assist Hebrews *en route* to America. The Jewish Board of Guardians was founded in London in 1859. According to the report of the British royal commission on alien immigration the policy of this Jewish Board of Guardians is to lessen the pressure of alien immigration upon England.

They persuade undesirables of their own race by circulars issued abroad, to embark for other countries than England, and if such undesirable persons arrive in England, render them assistance, and help them to emigrate to other countries. The majority of the undesirable Jews, thus persuaded and assisted, eventually land in New York. They are a hopeless, poverty-stricken people, fleeing anywhere, without object

other than to escape persecution in Russia or Roumania. When they finally reach New York, so complete is their pauperization, that they require assistance, in many instances for years after landing.

Thus the causes of emigration will be seen to indicate in most cases the relative desirability of emigrants. The best are likely to be found among those whose emigration is voluntary or spontaneous, and the worst are likely to be found among those assisted and pauperized by societies or rich individuals, while between the two extremes the others can be graded in varying degrees of desirability.

The first legislation relating to immigrants bears the date of March 2, 1819. A clause in this act provided for the enumeration upon arrival, as well as a statement of the age, sex and place of birth of immigrants. This provision of the law was expected to regulate the transportation of immigrants, to prevent overcrowding on the ships and to mitigate some other abuses on shipboard. Laws for regulation or restriction of immigration have always been the result of popular demand, and have been enacted from time to time either to correct existing abuses or to prevent the entrance of certain undesirable classes. The fact, therefore, that no immigration legislation was enacted from 1819 to 1875 speaks well for the immigrants arriving during that period.

It must not be supposed that the coming of immigrants was entirely unopposed during this period, but the clamor raised against them about 1850 was based on racial or religious grounds, was sectional, not general, and so manifestly selfish and bigoted that the great majority of Americans took no part in it, and no restrictive legislation resulted. About 1875 it became evident that some regulation of immigration was necessary in order to prevent certain undesirable classes, regardless of race, from landing. As a result the act of March 3, 1875, was recorded in the statutes. The classes barred by this act were prostitutes and convicted felons. By 1882 other undesirable classes attracted attention, and a law passed in that year added to the list of excluded classes, all idiots, lunatics, and 'persons unable to care for themselves without becoming a public charge.' It also provided that a head tax of fifty cents be collected from each arriving alien, the money to be paid into the treasury of the United States and to constitute the 'Immigrant Fund.' This fund was to be used in defraying the expenses incident to the regulation of immigration.

Previous to 1885, large employers of labor imported workmen under contract for less than the American standard of wages, and through the combined efforts of the labor organizations, legislation was enacted in 1885 to prevent the entrance of these contract laborers.

The first contract labor act of 1885 was strengthened by the amendatory act of 1887, by which power to make regulations and rules and issue instructions, not inconsistent with law, for the carrying out of the provisions of the act, was vested in the Secretary of the Treasury.

Up to this time the inspection of immigrants was made by state authorities, acting, of course, under federal law. This system was unsatisfactory, because of the lack of uniformity of inspection, and the difficulty of applying the law in imposing and collecting fines. It became evident that if an efficient uniform standard of inspection was to be established and maintained, it must be under the direct supervision of the federal authorities. The act of March 3, 1891, besides adding to the excluded classes, 'persons suffering from a loathsome or a dangerous contagious disease,' polygamists, and assisted immigrants, provided for the assumption of the work of inspecting immigrants by the federal officers. The office of superintendent of immigration was created, and the President was authorized to appoint such officer by and with the advice and consent of the Senate. The medical inspection was from this time to be made by officers of the Marine Hospital Service. This act also prohibited steamship companies from encouraging immigration by alluring advertisements, and provided for the deportation, within one year after landing, of any alien landed in the United States in violation of law.

The act of March 3, 1893, provided that the steamship companies should furnish lists or manifests made at the time and place of embarkation, which were to contain valuable information concerning the age, occupation, destination, moral and physical fitness, etc., of the immigrant. These lists were to be signed and sworn to by the master and surgeon of the vessel. This requirement of manifests was expected to cause a more careful scrutiny of passengers at the port of embarkation, and the manifests themselves would undoubtedly prove of great value to the inspectors in their work.

Under federal supervision the work of inspecting immigrants became more uniform and thorough. Suitable buildings had to be erected, and other expenses necessary to the rigid enforcement of the law were incurred. It became evident that the head tax of fifty cents was inadequate for defraying the expenses incident to immigration. By a provision in the sundry civil bill, approved August 18, 1894, the head tax was increased to one dollar.

In June, 1900, congress enacted that the commissioner general of immigration should have charge of the administration of the Chinese Exclusion Law.

After ten years of trial, the law of 1893 was found inadequate in some particulars, and a great popular demand for further restriction was manifested. As a result of this popular demand the law of 1903 was enacted. By the provisions of this act previous legislation was amplified, and further necessary restriction placed on undesirable classes of immigrants. The head tax was increased to two dollars. The authority to deport aliens landed in violation of law, was extended to a period of three years from the landing of such alien. In addition to

the undesirable classes excluded under previous laws, we find in this act that epileptics, and 'anarchists or persons who believe in or advocate the overthrow, by force or violence, of the Government of the United States, or of all Government, or of all forms of law, or the assassination of public officials' are excluded.

The utter disregard shown by the steamship companies for United States laws in permitting diseased persons to take passage for America, when their diseased condition must have been apparent, was responsible for the imposition of a penalty of one hundred dollars for bringing to our ports any alien suffering from a loathsome or dangerous contagious disease, which might have been detected by means of a competent medical examination, at the time of embarkation.

It will be noted from the foregoing summary of immigration legislation that nearly all the laws have been passed since 1880. It is a significant fact that previous to that time immigration came chiefly from Great Britain and Ireland, Germany and the Scandinavian countries. With the rapid and progressive increase of immigration from Russia, Austria-Hungary, Italy, and other countries of southern and eastern Europe, deterioration in the quality of immigration was sufficiently marked to indicate the necessity for more thorough regulation and restriction. The favorite method of evasion of our immigration laws was to send the questionable immigrant by way of Canada. By the courtesy of the Canadian government and by virtue of an agreement with the transportation companies our officers are permitted to examine, at Canadian ports, immigrants destined to the United States through Canada, but defective immigrants evaded this inspection by being manifested as destined to Canada. The Canadian law was formerly much less exacting than our own, and these people after landing and remaining in Canada a short time, could slip over the border without inspection. An effective system of border inspection was instituted by the United States immigration authorities, to prevent the smuggling of these immigrants across the Canadian border. The difficulty of guarding over three thousand miles of frontier can be appreciated, however, and the passage of a Canadian law (1902), at least approaching our own standard, has been welcomed as an addition to our defenses.

The provision made for excluding anarchists and persons of like tendencies has already been applied to some of these disturbers, and promises to be very effective in this direction.

Our contract labor laws have been materially strengthened by the act of 1903. There is no longer ground for misapprehension as to whether the laws were to apply to unskilled labor alone—or to both skilled and unskilled.

THE ROYAL PRUSSIAN ACADEMY OF SCIENCE AND THE FINE ARTS. BERLIN.

By EDWARD F. WILLIAMS,
CHICAGO, ILL.

IV. From the Reorganization in 1812 through the Reign of Frederick William III., to 1840.

THIS period was a period of great men in almost every branch of learning, especially in science, of great statesmen and historians, of great warriors and rulers. It was a period in which the intellectual life of Germany developed rapidly, in which the gymnasia were much improved, in which the new science of teaching was created, in which the universities, more especially those of Prussia, stimulated by the standards set up at Berlin, became worthy of a kingdom and the patronage the world has given them.

During the reign of Frederick William III., or from 1812 to 1840, the character of the academy changed very little. Its statutes were modified only when absolutely necessary, although under the influence of the Humboldts and their sympathizers it became, what it was organized to be, an institution for research, and through its publications, for the diffusion of knowledge. In the early decades of the nineteenth century Germany began to take her true place as a leader in scientific, historical and philosophical studies. She sought to make her own what Cousin, the French philosopher, describes as 'the true, the beautiful and the good.' The unity of all branches of learning became apparent. It was in this new era of intellectual life that some of the great undertakings for which the academy has acquired fame were planned and set on foot. Men like Niebuhr, Schleiermacher, Savigny and Boeckh felt the need of an institution which would consider and execute enterprises for the diffusion of knowledge which were far beyond the resources of private individuals. One of these enterprises, and one in which Boeckh was deeply interested, was the gathering, arranging and publication of Greek and Latin inscriptions. Out of the discussions in which Boeckh and many others engaged have come the volumes of Latin inscriptions to which Mommsen gave so many years of his life and which with their vast amount of information will ever remain a monument to his industry, scholarship and rare skill as an editor. The volumes of Greek inscriptions are of scarcely less value than those of the Latin. Another result of the departure from traditional methods has been the edition of the works of Aristotle,

including comments on his writings and such annotations by present-day scholars as have seemed necessary. It was through Wolff, one of the members of the academy, who died in 1824, that German scholars were made acquainted with the treasures of Grecian archeology. In the second decade of the century, great as was the ambition of many of its leaders, the academy was by no means what it now is. At its regular sessions rarely more than one half its members were present. Only 8 out of 29 or 30 who might have had the privilege heard Schleiermacher's remarkable essay on 'Various Methods of Translation.' The philosophical class, of which Schleiermacher was the head, contained only two members in addition to himself, Savigny and the younger Ancillon. It was the historical class which led the academy. To it belonged William von Humboldt, Ideler, Niebuhr, Buttmann, Boeckh and Bekker. In the decade following the fall of Napoleon the works of Savigny, the Grimm brothers, Lachmann, Bopp, Diez, Carl Ritter, Niebuhr, the Humboldts, Eichorn, Creutzer, Gottfried and Hermann appeared. Many of them were epoch-making. Schleiermacher represented philosophy, philology and theology, as well as ethics, in his writings and in his instructions as a professor in the university. Boeckh represented philology, history and economics, while Niebuhr made it plain in his Roman History how history should be studied and written. Savigny indicated in his writings on law how closely united it is with history and philosophy.

It was in 1815 that Boeckh proposed and secured the adoption of a plan for the publication of all accessible Greek and Latin inscriptions. He thought the work might occupy four years and cost about $450. It is not yet entirely complete and has cost more than $45,000. Boeckh gave his personal attention to Grecian antiquities and with the aid of a commission appointed by the academy, by correspondence with societies in Corfu, Thessaly and Athens, and by searching the libraries of Europe, gathered material for a work which he soon discovered would be far more extensive, valuable and costly than he had originally anticipated. Bekker came to his aid and was made his permanent assistant in 1817. He had spent the years 1810–12 in Paris, copying manuscripts, and in 1815–16 had been employed with Professor Goeschen in Verona in copying the 'Gaius,' discovered by Niebuhr while serving as ambassador in Rome, a work which has proved to be of importance for the science of law. In 1817 Bekker was entrusted with the preparation of the writings of Aristotle, which was subsequently made to include the comments and everything else which could throw light upon their meaning or their importance. Professor Brandis was chosen as his assistant. This edition, now under the care of Professor Diels, is approaching completion and is of inestimable value to all who prize learning and painstaking accuracy. Mr. Diels entered the academy in 1882 and is still one of its most important members. Bekker devoted

the years 1817–20 to careful study of the material in the libraries of Italy, Holland, Belgium and France as a preparation for his editorial work, which began in April, 1821. Although it was decided as early as 1817 that an edition of Grecian inscriptions should be published, nothing was actually done to bring this about till 1826. Prior to this last date it had become evident that it would not be enough to publish inscriptions which had already appeared, as Zumpt proposed, or were in the libraries, but that all of them must be copied anew from the ruins and monuments on which they were found and then patiently studied and criticized by the best scholars of the day. For defraying the cost of this undertaking, a grant from the government was sought and obtained. A third work of very great importance interested the academy and received a good deal of assistance from it, the Monumenta Germaniæ. So important was this work that the Society for the Study of Old German History was organized to care for it, a society in which all German-speaking countries have shown an interest. A long step forward was taken by the academy in 1821, when it secured a printing-press of its own, with fonts of type in Arabic and Sanscrit as well as in Greek, Latin and German. Of course, there were troubles with the printer, but it was now possible for the academy to watch closely its own work and to send it out into the world in such shape as it desired. Henceforth the 'Transactions' or 'Proceedings' appeared in a greatly improved form.

There were many serious discussions among the members of the academy as to the wisdom of retaining four distinct classes, each with its own special secretary or director. Some like Schleiermacher wished the number reduced. He did not care to have the philosophical class continued. He and its members preferred to be in the historical class. Others thought science had been neglected, although as many men prominent in its various branches as could be persuaded to come to Berlin had been invited thither as members of the academy or as professors in the university. Minister Altenstein in 1820 sent an order to the academy to put a statement of the changes it desired into writing, but with the understanding that the philosophical class would be retained, and the historical class, if possible, be made more efficient. That meant that the four classes would be continued substantially as they were.

Meanwhile the government had grown suspicious of Schleiermacher and Savigny. They were looked upon as 'demagogues and spies.' The police were ordered to listen to Scheiermacher's sermons. William von Humboldt was dismissed from the cabinet as Cultus minister because of the liberality of his views, and the academy was rebuked for publishing such papers as those of Niebuhr. A decree was issued on October 19, 1819, by order of the king, which forbade any member of the academy to publish anything, whether literary or scientific, without

the approval of the government censor. Thus the right of free publication, which the academy and its members had long enjoyed, was invaded, and in spite of protestations, freedom of publication was suspended for five years, and was not formally removed till July, 1843. But a petition for freedom on the part of the academy to issue its official papers without submitting them to censorship was favorably received by the king, although that privilege was denied to its members as individuals.

The physical class of the academy, stimulated by what the historical class had accomplished, set itself about great enterprises. In 1820 it sent Ehrenberg, who had already won fame as a microscopist, to Egypt. He and Hanpricht, his associate, explored the Libyan desert, Lower Egypt, Upper Egypt as far as Nubia, the coast of the Red Sea and passed through Arabia, Petrea and Syria. To the funds required in 1823 the king made generous gifts from his private resources. The year 1825 was given to travel and study in Abyssinia. In the 85 boxes sent to Berlin at different times there were geological specimens of great variety, many fossils, a large selection of dried plants, as well as of woods, fruits, seeds, weapons and instruments in use in northern Africa. Of animals there were above 4,000 different specimens in ten times that number of individual examples, and 2,900 specimens of plants. This journey and its outcome were significant for both the academy and the progress of science.

The scientific section of the academy put forth a special effort in 1825 to strengthen its influence by securing men of the first rank for its various departments. As the astronomer had failed to keep abreast of the times, Oltmans and Encke were brought into the academy. Encke served it forty years, and till 1863 was secretary of the mathematical class. It was through his influence and discoveries that the academy gave such an impulse to astronomical studies. The new building for astronomical uses, begun in 1832, was completed in 1835, and $375 a year for six years was set aside by the government for its support. A map of the heavens was planned, on which the position of all fixed stars above the ninth and tenth magnitudes was to be shown. The heavens were divided into 24 sections and assigned to as many observers. It was supposed that the map, which was a pioneer of its kind, would be completed in four years. In fact, it was only partially completed in 1859, but it prepared the way for the more accurate and extensive work of later days. Not a little was done by the historical class in archeology, and the need of special funds and accurately trained laborers in this field was seen to be so pressing that in 1829 the Archeological Society of Berlin was formed. Aid was given Graff for a German dictionary and to Bopp for an edition of the Indian poem, 'Mahabharata.'

Hegel's philosophy with its theories of panlogism and its doctrine

of the absolute, was not favorable to science. Yet it enjoyed the confidence of the government and in many circles was accepted as true. But to Schleiermacher and not a few others its theories seemed fanciful and uncertain. Perhaps it was on account of their unwillingness to receive him into the academy that in 1826 he and a few others founded a society for scientific criticism with the three departments of philology, philosophy and history. This society, to which some distinguished men attached themselves who might otherwise have been in the academy, till some time after the death of Hegel was influential in Berlin. Regular sessions were held, and year books, two volumes each year, from 1827 to 1840, were published.

It was in this last year that the philosophical class, now reduced to two members, was given up, and its work transferred to the historical class, of which, since Buttmann had become too old to discharge its duties, Schleiermacher became secretary. During the first third of the century the philosophy of the absolute had the field. It was in the second third of the century that natural history and religion entered the lists against it and won the victory. And yet the reign of science in Berlin began with the return to that city in 1827 of Alexander von Humboldt, who had lived twenty years in Paris in close association with Liebig, Arago, Gay Lussac, Bonpland and Valenciennes, to all of whom he was warmly attached. At that time the academies of Paris were at the height of their fame, as eminent in their different fields as the university of Paris had been in the middle ages among the other universities of Europe. Humboldt had rare skill in gathering and grouping facts, and the publication of his 'Cosmos' was a great event in the scientific world. Yet its leaves were hardly dry from the press before its conclusions were outgrown. But the spirit and method of the book, writers like Harnack say, will survive.

The winter of Humboldt's return was full of excitement for learned circles in Berlin. In the university he lectured on the 'Cosmos,' and sixteen times he spoke on the physics of the world to an audience which filled the Singakademie and represented every class of society from the king to a stone mason.

Between 1830 and 1840 many of the more prominent and useful members of the academy passed away—Niebuhr, Seebeck, Rudolph, Schleiermacher, William von Humboldt,—and new men were added—Dirrichlet, Ranke the historian, Eichorn the critic, Hoffman the statesman, Graff, Stein, Johannes Müller, G. Rose, Gerhard, Dove the meteorologist, Poggendorf, Neander the church historian, and Magnus —every one of whom contributed not a little to the increase of knowledge and to the fame of the academy.

For some reason the physical class was now growing more rapidly than the historical class, for there had in reality ceased to be more than these two classes, and efforts were made in the early thirties to

render them more nearly equal. But the objection to Hegel on the part of many, and the admiration felt for him on the part of others, made it well-nigh impossible to elect any one to the historical class. This abnormal condition of things was brought to an end by the sudden death of Hegel on November 14, 1831. A commission was appointed to see if some means could not be devised for reducing the four so-called classes of the academy to two, a mathematical-physical class and a historical-philosophical class, the arrangement which now exists, but which was not brought about till 1838, although the difficulties between the classes had long before passed away. By special decree on March 31, 1838, many desirable changes were favored and made legal by the king. In 1837 it had been definitely decided that the academy should stand for research, chiefly in science and literature, that the number of members should not exceed fifty, equally divided between the classes, and that each class should nominate only one hundred corresponding members. The mathematical-physical class voted to have two members each for chemistry, physics, botany, zoology and anatomy, and six for the mathematical sciences. In May, 1839, the historical class proposed three members for the study of philosophy and its history, three for the study of general history, two each for archeology, mythology and oriental literature, four for the old classical literature, one member for the study of German philology, and one for the study of politics.

With this arrangement of its forces the academy could now be defined as 'a society of learned men organized to advance and spread general knowledge apart from the function of teaching.' It was agreed that each class should determine and direct its own work, that special meetings for each class should be held once a month, general meetings each week, that no person should belong to two classes at the same time, that each class should propose its own members, though they must be elected by the vote of both classes of the academy and that vote confirmed by the king. The right to lecture in any Prussian university was made one of the perquisites of members of the academy. Ordinary members were paid $50 a year, the botanist, the chemist, the astronomer, two philologists and two historians, more than twice as much. The four secretaries while managing their special sections were to preside in turn at general meetings four months each.

Three public meetings were appointed for each year, Frederick's Day in January, Leibniz Day in July and the king's birthday. For January the program was to be a general history of the year; for July, an account of the special work done. Persons not belonging to the academy could be employed for special service, but only two men at a time for each class, and not more than $300 a year could be paid out for this kind of work. With slight modifications these arrangements and regulations are still in force, although the members are paid $225 (900 Marks) each a year, and divisions into sections in the

academy made for convenience and efficiency are all now embraced in the two classes already named. The king died in 1840. At that time the income of the academy from all sources was a little more than $15,000. It had not increased materially since 1809, and yet out of this small income some money had been saved and invested as capital. The king had preserved the independence of its members save in regard to the censorship exercised over their private writings, and had entrusted its care to wise advisers. During this reign, advance in knowledge, especially in scientific directions, had been very great. The academy had done some excellent work in all the departments of knowledge which it represented. In mathematics, worthy of mention are Dirrichlet, Steiner, Weierstrass, Jacobi and Kummer. When only twelve years, Dirrichlet spent his money for books on mathematics. From the Cologne gymnasium he went to Paris to hear La Place, Legendre, Forier and Poisson. He not only could understand Gauss's 'arithmetical disquisitions,' but he could make their meaning clear to others. He married Rebecca Mendelssohn Bartholdy in 1832, and after that time till his death his house was an intellectual and social center in Berlin. In the estimation of those who know it best his work was as important as that of Descartes in the use of analysis in geometry. Astronomy made good progress under Encke. His study of the occultation of Venus in 1796 enabled him to determine more accurately than had ever been done the parallax of the sun. In physics many names have become famous. Paul Ermann and Seebeck were in the academy before Frederick William III. occupied the throne; Dove, who laid the foundation of the science of modern physics; Poggendorf and Magnus came in prior to 1840. Ermann was in the academy from 1806 to 1851, was one of its secretaries from 1810 to 1841 and did as much as any one to help forward its development. DuBois Reymond was accustomed to speak of him as one of the best physicists of his era and as preparing the way for physicists like Magnus, and physiologists like Johannes Müller. Magnus was trained in chemistry by Berzelius and Gay Lussac, and in his turn trained many of the best modern chemists of Germany. Seebeck, after laboring thirteen years in the academy, withdrew to Jena, living upon his private means and devoting himself wholly to scientific studies. Mitscherlich, the discoverer of isomorphism, and Heinrich Rose, the discoverer of niobium, were trained by Berzelius and as analytical chemists have been ranked with their teacher. J. B. Karster, Weiss and G. Rose were eminent as mineralogists, and Leopold von Buch is credited with having laid the foundation for the study of geology and paleontology in Germany. His geological map in twenty-five leaves, published in 1821, had in 1843 run through five editions. For many years Link was the keeper of the botanic garden in Berlin, and with his own money founded its present magnificent herbarium. Harkell and Kunth were associated

with him in his work. The latter spent sixteen years in Paris on a collection of plants carried thither by Alexander von Humboldt, and at his death left a herbarium containing 55,000 specimens, which the government was wise enough to purchase. Zoology and anatomy were represented in the academy by Rudolphi, Lichtenstein, Ehrenberg, Klug and Johannes Müller. The first named was director of the zoological museum, which he made the finest in Europe. He was author of 'Journeys in South Africa.' Klug worked in entomology for more than half a century, and at his death left the museum more than 80,000 species of insects in more than 260,000 specimens. He gave no little attention to the study of spiders and shells. Ehrenberg is famous throughout the world as a microscopist. The titles to his papers, his reports to the academy and his works fill twenty-five pages in the quarto catalogue of the academy. In anatomy and physiology the studies of Müller, who was twenty-five years in the academy, were epoch-making for the science of biology. It is admitted that he made physiology a science. Alexander von Humboldt was recognized as the most distinguished man of science of his generation. Devoting himself to no single department of science, he became eminent as a man of almost universal knowledge. At his death the king consented that his friends should establish a fund in his memory, the income of which is available under the direction of the academy for journeys in various parts of the world in the interest of such studies as Humboldt himself had most eagerly pursued. Carl Ritter was the founder of the scientific study of geography. Ideler combined the study of modern languages, in which he was an adept, with the study of mathematics and astronomy. F. A. Wolff gave himself to philology, a science which he did a great deal to form and develop. Niebuhr, Buttmann, Boeckh, Bekker, Suesmilch were ornaments to the academy. The last named was followed by Lachmann and Meineke, and these in turn by Hirst and Uhden, who began the study of archeology, which E. Gerhard did so much to push forward into the prominence it deserves. In Rome Niebuhr gathered many manuscripts, which were of use in the preparation of the Latin inscriptions. Though a librarian, Buttmann gave himself to lexicography and grammar. While England and America are deeply indebted to him for his 'Grammar of the Greek Language,' which first appeared in 1820, it is not too much to say that he made the study of that language popular and scientific for his native land. Lachmann, who lived from 1793 to 1851, was a born critic. He was a student of old dialects of modern languages, as well as of the classics and of the text of the New Testament. Zumpt was distinguished as a Latinist and for his grammar of that language. E. Gerhard was famous as an archeologist, but was most useful in carrying through Mommsen's plan for gathering, collecting, arranging and publishing the Latin inscriptions. Francis Bopp came to Berlin at the suggestion

of Humboldt and was made professor of oriental languages in the university. He devoted himself mainly to Sanscrit, and published his dictionary of that language in 1827. The first part of his 'Comparative Grammar,' by which his fame was gained, appeared in 1852. Other editions appeared at different times from 1856 to 1862, and the last edition shortly after his death in 1868. To him all orientalists owe a debt of gratitude. Jacob Grimm gave himself to the study of the German language and William von Humboldt to the study of the philosophy of language, in which his writings are as important for the science of law as those of Linnæus for the science of botany. Every one knows what Niebuhr did for history, which he studied in the belief that knowledge of it is of value for the present day. Boeckh found his chief interest for the time in which he lived, in the study of life and government among the ancient Greeks. Bekker was famous for his studies of Homer, his editions of Provencial works, his studies in old French and Italian and in modern Greek. From him Lachmann learned the true method of criticism. Wilker and Friederich von Raumer were students of universal history, the latter being known for his 'History of the Crusades.' Savigny and Eichorn were historians of law, as Niebuhr was of Rome and Neander of the church. Savigny is the founder of the historical school of jurisprudence, and immortalized himself in a six-volume history of 'Roman Law in the Middle Ages.' K. E. Eichorn is the father of the history of German law. Von Ranke, who died in 1886, stands at the head of modern historians. As he went to the original sources for what he wrote, his books will not soon lose their value. Hoffmann, the statesman, became famous as a statistician and a political economist. It is said of him, as of no one else in his time, that he knew how to arrange statistics scientifically and to deduce ethical lessons from them. He was director of the Prussian bureau of statistics and made it one of the most valuable in Europe. These are some of the men who were in the academy during the period under treatment and whose names are sufficient to furnish reasons for the fame it attained and for the share it had in contributing to the knowledge of the world. Indeed it has been proudly said that no volume of the 'Proceedings' during this period is without some treatise which either founds a discipline or lifts an older one to a higher grade.

V. The Academy under Frederick William IV., 1840 to 1859.

Not since the days of Frederick the Great had there been so warm a friend of the academy on the throne as the new king. He was willing to identify himself with the academy by attending its public meetings as Frederick had not been. Save in the realm of politics and theology he granted it full liberty of discussion and publication. He was very friendly with Alexander von Humboldt, whom he had as a

constant guest at his table, through whom he kept himself informed as to the progress of science in Europe and the special needs of the academy. He favored the new learning and the new methods of study, but he did not favor radical measures in politics nor changes in the creeds or in the methods of governing the church. Yet he brought the Grimms, Haupt and Mommsen to Berlin, radical as he knew them to be in their political opinions, and secured their election to the academy. From him came the money for the publication of the Latin inscriptions and for the beautiful and complete edition in thirty volumes of the works of Frederick the Great, Vol. I. appearing in 1846 and Vol. XXX. in 1856. He interested German scholars in Egyptian research and made it possible, by private gifts, for Lepsius to spend the years from 1842 to 1845 in the study of its monuments and its curious learning. He helped Agassiz to come to America, Rosen to go to the Caucasus, Petermann to Syria, Palestine and Arabia Petrea, and Peters to South Africa. He aided Graff on his Old High Dutch collection and Schwartze in his Coptic studies. He provided means with which Dove pursued his meteorological researches and for the establishment of institutes in connection with the universities for the training of teachers. In 1842 he founded the order *pour le mérite* and the Verdun prize to be given once in five years for the best German book issued during that period. It is interesting for Americans to know that this prize was awarded to the late Professor von Holst for his 'Constitutional History of the United States.' And yet the relation of the academy to the government was not quite so pleasant as it had been during the ministry of Altenstein. The new ministers were not all so profoundly convinced of the usefulness of the academy as was the king, but they did not fail to aid it or cease to advise the king to sustain it. At his death the great work on German inscriptions, to which he had given much thought, was approaching completion.

In passing, it may be observed that the first written word ever sent the academy by Mommsen was in a letter of thanks, dated April 2, 1843, for a grant of a little less than $120 for aid in his studies of Latin inscriptions in and about Naples. One of his last reports was read in the academy in 1903. Not only was the academy with great difficulty persuaded to undertake the publication of the Latin inscriptions, it was with still greater reluctance that it entrusted the gathering and arranging of them to so young a man as Mommsen. He was backed by men like Savigny and Lachmann, and the first installment of his work proved even to those who had doubted it his fitness for the undertaking. Yet it was not till seven years had passed, called by Gerhard his 'seven years' war,' that Mommsen was finally given entire control of the work, with power to choose his own assistants and proceed in his own way. Meanwhile he had sent the academy 450 inscriptions, most of them copied with his own hand, 100 of which

could not be found in the libraries of Europe and 150 of which had never been published. During the discussions concerning himself and his relation to the inscriptions he retired to Leipzig as a professor and thence to Zürich, where he began his 'History of Rome.' In his new work in the 'Inscriptions' Italian scholars freely offered their assistance, some of them without asking for pay, so that when the king pledged $2,000 a year for six years there was no reason for hesitating to send the young scholar back to Italy. In 1857 he was transferred from Breslau, where he had been made a professor, to Berlin, given a chair in the university and elected to active membership in the academy. He became one of its most useful and prominent members, and at his death in 1903 was one of its most famous. Vol. IX. of the Latin inscriptions was published in 1862, and in the same year the 'Monumenta Priscæ Latinitatis.' Each year of this reign from $1,500 to $1,750 was expended, apart from special grants, for purely scientific purposes. Yet, in spite of its limited means, never exceeding $15,000 annually, the savings of the academy in 1857 had reached the sum of $25,000.

The death or withdrawal of many of the older members of the academy and the introduction of new members, many of them young men, brought a great change into its spirit and methods. The Grimm brothers were in the academy thirty years and did very much to increase its usefulness and its reputation. The second edition of Jacob Grimm's 'German Grammar,' the first edition appearing in 1822, contains his law of sound and gives its author a place by the side of William von Humboldt and Francis Bopp as one of the founders of the modern science of language. After the death of Stein, G. H. Pertz was entrusted by the Society for Old German History with the editorship of the 'Monumenta Germaniæ,' a work which but for his diligence and his skill might never have been finished. It was through his advice and persistency that the academy was induced to publish the 'Annals of Leibniz.' In 1844 Jacobi, second only to Gauss as a mathematician, was brought from Königsberg to Berlin and the academy. He devoted himself to the study of the functions of the ellipse. His writings for six years fill two of the quarto volumes of the academy. Trendelenberg, whose strength as a philosopher lay in his skill as a critic, and in his knowledge of all previous thought, was instrumental in inducing the academy to undertake the publication of the works of Aristotle. Peterman was famous for his acquaintance with the Armenian, Semitic and Coptic languages, and Homeyer for his studies in the middle ages and for his ability to trace in a scientific manner the history of law during that era, and to give his contemporaries a correct understanding of the history and development of German law. Of what Lepsius did for the science of Egyptology few are unaware. During the fifties the zoologist Peters; the physiologist DuBois Rey-

mond; Kosch and Baum, the botanists; Buschmann, the linguist; Pinder, the numismatist; Riedel, the historian; Curtius, linguist as well as historian; Kiepert, the geographer; Haupt, the philologist; Beyrich, the geologist; and Ewald, the paleontologist,—entered the academy and by the investigations in their special departments of study and their publications did their full share in increasing its fame throughout the world. When DuBois Reymond was a candidate for the academy, Alexander von Humboldt and Johannes Müller, his backers, described him as 'a fine experimenter in physics, physiology and chemistry' and added that 'he had been carefully trained in mathematics and the classics.' Reymond became one of the best known members of the academy, was in it forty-five years and lived for it as no one had done since the days of Merian. In 1850–51, Barthomess of Frankfurt, an honorary member of the academy, published what Harnack describes as a philosophical history of the academy. It covers the period from Leibniz to Schelling, and within its limits, Trendelenberg says it is unsurpassed. Notwithstanding the excitements in Berlin, as well as elsewhere on the continent of Europe, of the year 1848, and the anxiety caused by the failing health and the mental weakness of the king nearly a decade later, the members of the academy quietly performed their tasks and through its publications added something every year to the aggregate of human knowledge. Not a few of its members were recognized throughout the world as leaders in the departments of study to which they had devoted their energies. Alexander von Humboldt, who died in 1859, having been connected with the academy, either as honorary or as active member, since the beginning of the century, was present at one of its regular sessions in March as eager for knowledge as in his youthful days. With his death and that of Carl Ritter and William Grimm a great era in the history of the academy closed. But before entering upon that chapter of its history which unites it with the present, we may call attention to the fact that in 1845 Prescott, Sparks and Bancroft, American historians, were made corresponding members, that in 1852 Dr. Edward Robinson, the distinguished biblical scholar, was added to the list, and that in 1855 the same honor was accorded to Professor James D. Dana, the geologist, and Professor Asa Gray, the botanist.

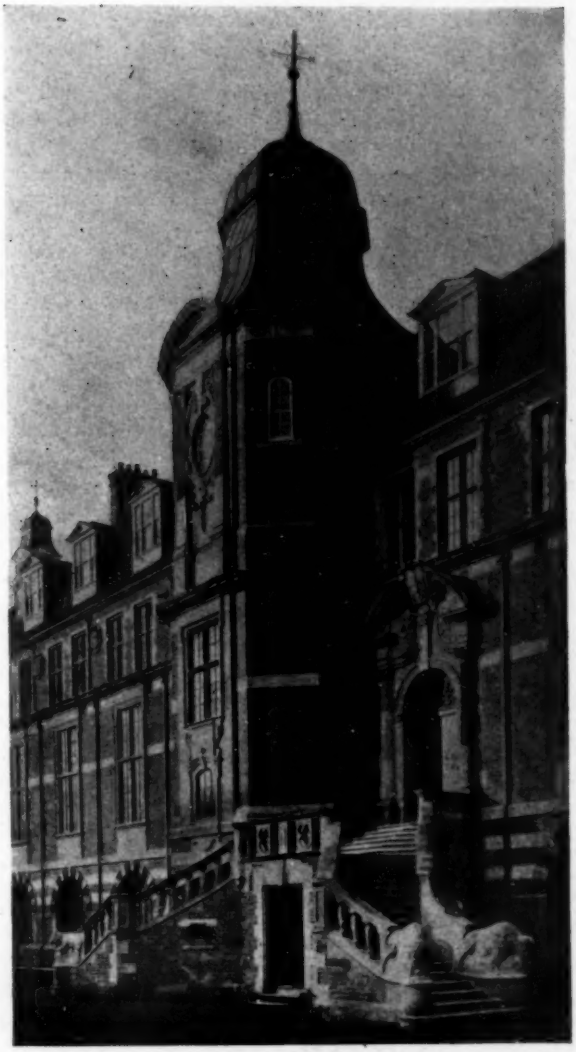
THE PROGRESS OF SCIENCE.

THE NEW BUILDINGS OF CAMBRIDGE UNIVERSITY.

On the first of March four new buildings were opened at Cambridge by King Edward. One of these is a law school; the others are for the natural sciences—a medical school, a botanical laboratory and a geological museum. The great English universities have found difficulties in meeting the requirements of modern science. The colleges were richly endowed, though unequally; and they have suffered in recent years from the depreciation in the rents of agricultural lands. The lecturers and coaches of the colleges could give the instruction needed in the languages and in mathematics, and to a certain extent in other subjects such as the political and mental sciences, but they could not provide laboratories for the natural sciences. The universities were almost without endowments, and they have been very slow in coming either from the state or from private gifts. In 1882 a commission required the colleges to contribute toward the support of the university. In 1897 special efforts were made at Cambridge to secure an endowment fund, which resulted in gifts amounting to about $350,000, rather a modest sum, according to American ideas, but sufficient with the other resources at hand to warrant the erection of four new buildings.

Geology at Cambridge had its beginnings in the bequest of Dr. John Woodward, who in 1727 drew up a will leaving to the university his cabinet of fossils and an income of £150, from which a lecturer was to be paid to read at least four lectures every year in defense of the doctrines of the founder. It appears that lecturers were duly appointed who did not lecture, until in 1818 the office was assigned to Adam Sedgwick. In the following fifty-five years, Sedgwick made Cambridge a great geological center. After his death in 1873, a committee collected a fund ultimately amounting to about $125,000, to which the university added about $100,000, and the Sedgwick Memorial Museum has been built from designs by Mr. T. G. Jackson. Professor Hughes, Sedgwick's successor in the Woodwardian chair, says of the building: "Skilfully designed, and carefully executed, it will enable us to display the finest educational collection in the world. This was what Woodward aimed at in his day of small beginnings, and what Sedgwick worked for during his whole academic career. The great museum occupies the first floor of both wings, and amid the long series of specimens which scientific geology has revealed to us, Woodward's ancient cabinets are piously preserved in a small enclosure special to themselves. On the ground-floor are the products of the earth's crust which are of economic value, with a large lecture-room. On the second floor are class-rooms, and private-rooms for the different teachers, with the noble library, the fittings for which were provided by the liberality of the late master of Trinity Hall. In the attics are more rooms for research, and large store-rooms where specimens can be unpacked, sorted, and determined before they are placed in the museum."

The building for the botanical school is less imposing than the Sedgwick Museum, but appears to secure good effects by its proportions. So far as can be judged by the illustrations and ground plans, it presents a good type of laboratory building, with ample light and convenient arrangements. The build-

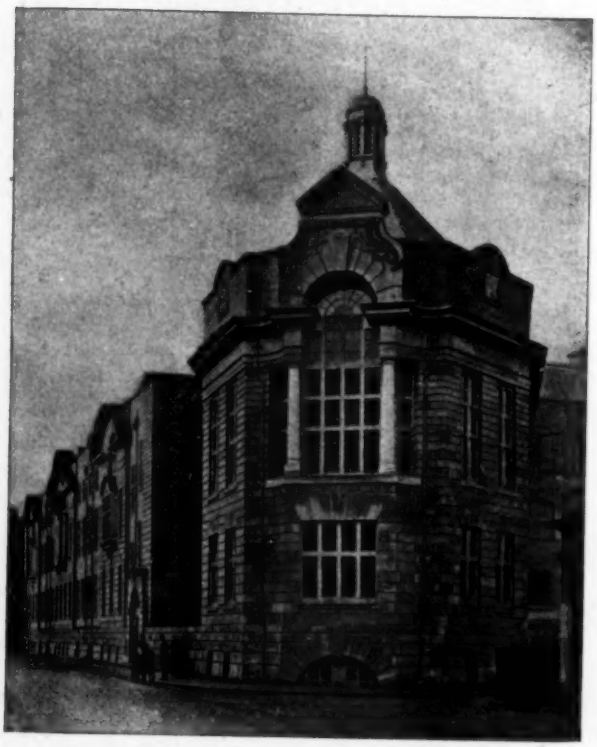


THE SEDGWICK GEOLOGICAL MUSEUM.

ing has doubtless been made for the laboratories and lecture rooms, not as sometimes happens in university architecture, imitated from some model built at a time when there were no laboratories. A hundred years hence such buildings will probably appear in better taste and more truly beautiful than our gothic and classic imitations, built without reference to their uses. The cost of the botanical building paid from the endowment or benefactors fund mentioned above is about $130,000. It contains in addition to the herbarium and museum and a large elementary laboratory, laboratories for physiology, morphology and chemistry, and some ten private and research rooms. The engineering department has taken over the room formerly used for botany.

The Medical School Building with

THE BOTANICAL LABORATORY.



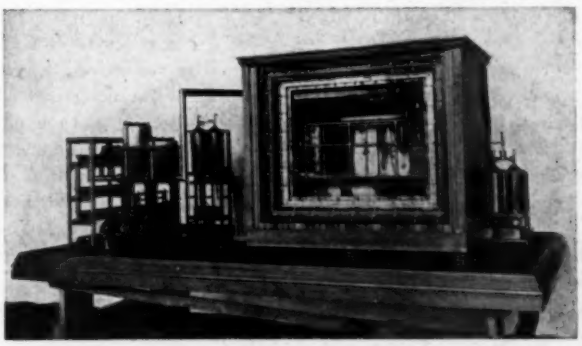
THE HUMPHRY MUSEUM AND THE MEDICAL SCHOOL.

the Humphry Museum has been erected at a cost of about $170,000, mostly supplied by the benefactors fund, and a further wing for pathology and physiological chemistry is planned at a cost of about $65,000. The Humphry Museum is treated ornamentally, both inside and out. The fact that the main lecture-room is lighted entirely by artificial light, might lead us to suppose that utility had been sacrificed to architecture, but it is said that the building is well adapted to the uses of the medical school. The library is planned on a new principle, the stacks being blocked solidly on the sides, each case being movable and pulled out when wanted. This scheme seems to be ingenious; the space is nearly trebled and books are kept free from dust. It is doubtless a disadvantage to shut the books from view, but when the case is pulled out the books are more accessible than in ordinary stacks.

The buildings here mentioned are erected on land acquired by the university from Downing College, and three of them form part of an irregular quadrangle. It is hoped that a school of agriculture and an archeological museum will be added to the group within a reasonable period.

DEVELOPMENTS IN THE RESPIRATION CALORIMETER.

Two important developments have lately been made in this apparatus, which render it a more efficient means of determining the use which is made of food nutrients in the body, and extend its use to experiments with large animals. As is well known, the apparatus as developed by Atwater and Rosa enabled the accurate determination of the carbon, nitrogen and water excreted by the subject within the respiration chamber, and the heat given off by him under different conditions of food and exercise. During the past year an alteration has been made in the apparatus by which the oxygen consumption is also determined, giving increased accuracy and furnishing data for estimating the gain or loss in protein and fat, as well as a new method of estimating the respiratory quotient. The arrangement for determining the oxygen is new and very ingenious. In adapting the apparatus to it, it has been changed from what is known as an 'open-circuit' to a 'closed-circuit' apparatus, *i. e.*, the same air is used over and over again, the products of combustion in the body of the subject (carbon dioxide and water) being constantly removed by passing the air current through sulphuric acid and soda lime, and fresh oxygen supplied to take the place of that consumed in the respiration. The oxygen content of the air current is kept practically constant and normal. The accuracy of the modified calorimeter for measuring heat has been tested by a number of electrical check

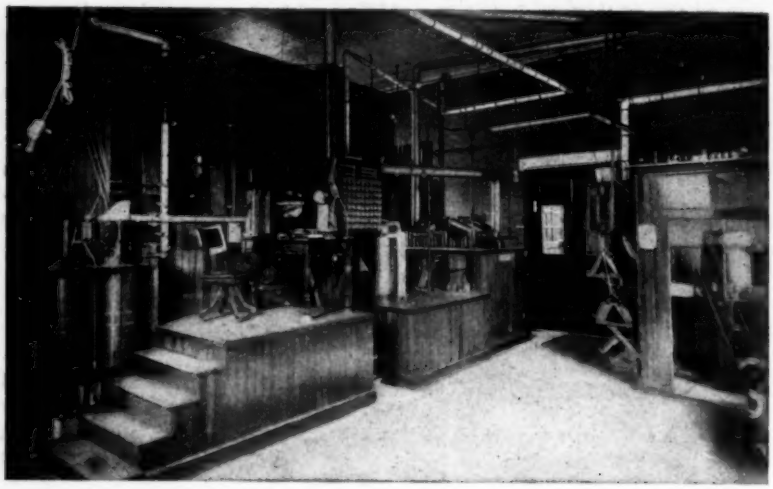


MODEL OF THE ARMSBY-FRIES RESPIRATION CALORIMETER.

experiments, and by the combustion of alcohol in a specially devised lamp.

As indicating the character of the work carried on by Professor Atwater with this apparatus, a recent experiment may be cited. In this the subject remained in the respiration chamber for thirteen consecutive days, making the experiment the longest one on record and in many respects the most complete. There were three days of work on a so-called sugar diet, three days on a fat diet, one day of hard work on a fat diet, two days of fasting, and four days on a light and very simple diet, the subject sleeping or lying down during one day, sitting up one day, and two days doing light work on a bicycle provided with an ergometer for measuring the work. The observations were unusually complete, including in addition to the carbon, hydrogen and heat, the oxygen and the income and outgo of sulphur and phosphorus. A record of the body weight was also made by a new method in which the subject was weighed from the outside.

The adaptation of the respiration calorimeter to use with farm animals marks a decided advancement in the method and facilities for studying the fundamental principles of animal nutrition. This has been accomplished by Dr. H. P. Armsby and J. A. Fries, who, working in cooperation with the Bureau of Animal Industry of the Department of Agriculture, have constructed an apparatus of this type at the Pennsylvania Experiment Station. In adapting the apparatus to experiments with large animals, it was necessary not only to increase the size of the respiration chamber, but to introduce a considerable number of special features so that the operations of feeding, weighing, collecting the excreta, etc., could be performed entirely from without. Among the most interesting of these are the devices for weighing the heat absorbers from the outside, the air lock for introducing feed and water without allowing the escape of air from the respiration chamber, and similar devices for the collection of the liquid and solid excretory products.



ARMSBY-FRIES RESPIRATION CALORIMETER.

By check experiments the apparatus has been found to be very accurate, the measured heat being practically identical with the theoretical amount produced by burning alcohol in the respiration chamber. In ordinary

METER PUMP AND ABSORPTION TUBES (ARMSBY-FRIES APPARATUS).

metabolism experiments with animals the amounts and composition of the food and of the urine and feces are the factors considered. Using this apparatus it is possible to determine the total income and outgo of both matter and energy. The apparatus affords opportunity for investigation in a great variety of important lines, and for checking the results secured by the more practical feeding experiments. It is especially adapted to studies of such questions, for example, as the energy required to digest and assimilate different classes of feeding stuffs, the food requirements of animals under different conditions, and the replacing value of nutrients.

An experiment recently reported with the apparatus, the first one to be published, was on the available energy of timothy hay. In this a large steer was used, and there were four periods, each covering two days in the respiration chamber. This first experiment gave results of much interest from both a scientific and a practical standpoint, and clearly demonstrates that for studies on the nutrition of animals, as well as of man, the possible lines of investigation with the respiration calorimeter range from the most practical to the most technical subjects.

It is worthy of mention that the Armsby-Fries apparatus is a distinctly American product, and is the only one of its kind in operation in the world. A similar apparatus, modeled after it, is being constructed at the agricultural academy in Bonn, Germany, but is not yet in operation.

THORIUM, CAROLINIUM AND BERZELIUM.

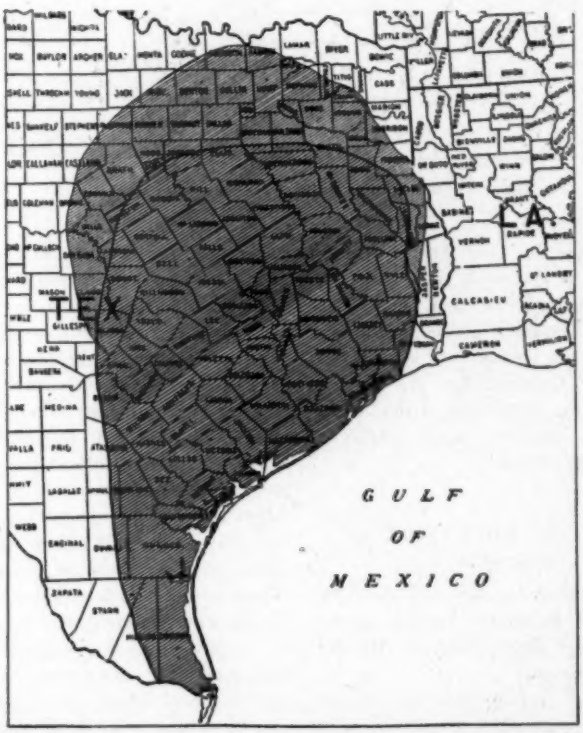
In a paper entitled 'Thorium, Carolinium, Berzelium,' presented at the Chemists' Club, New York, the evening of April 8, by Dr. Charles Baskerville, professor of chemistry at the University of North Carolina, the following interesting and important facts were brought out. As the result of a number of years' study of the element thorium, Dr. Baskerville has succeeded in extracting from it two novel chemical elements. The work indicated an agreement with the conclusions of Hofmann and Zerban in opposition to those of Schmidt, Curie and Rutherford, namely, that thorium is a primary radio-active body. Although no thorium preparations had yet been prepared absolutely free from any activity, numerous reasons were given which pointed toward the correctness of the conclusion that thorium is not a primary radio-active element. An extremely interesting observation touching this may be noted, namely, a preparation was obtained from a large amount of the wash waters used in the manufacture of the Welsbach mantles which was very much more radio-active than the original thorium and yet showed no thorium by chemical methods, and the merest trace was found in the spectrum made with a large Rowland grating. Whether it be primarily radio-active or not, the speaker maintained would not interfere with the other conclusions obtained from the investigations of himself and a number of his students.

Pure thorium was fractioned by phenyl hydrazine and the fractions obtained varied in their atomic weights from 214 to 252, the original thorium showing 232.6. That method was abandoned as time-robbing, and an effort was made to separate the constituents by fractional distillation of the chlorides as they were made by passing chlorine over a mixture of pure carbon and thorium dioxide. Very elaborate apparatus was devised for this purpose, the mixture being placed within a carbon boat and the distillation carried out within quartz tubes. A white vapor was given off at a comparatively low temperature which condensed in the cooler portion of the tube and was readily collected by solution in alcohol. The thorium was distilled away from the boat and collected as fern-like crystals of the tetrachloride within the quartz tube. A residue remained in the boat. These three materials were more or less purified and atomic weight determinations made of them. That which remained in the boat after different methods of purification showed an atomic weight of 255.6. Its oxide gave a specific gravity of 11.26, the original thorium having an atomic weight of 232.6 and specific gravity of 10.5. The original thorium oxide was pure white, whereas this residue possessed a pinkish tinge. This is the carolinium of the new element reported by Dr. Baskerville in 1900. The volatile body gave an atomic weight of 213, assuming its quadrivalence. The oxide gave a specific gravity of 8.44. It possesses a slight green color. As Berzelius first noted this 'Meisserdampf,' stating that it was not thorium, the author named the element berzelium after the famous Swedish chemist who discovered thorium. The new thorium gives a white oxide and shows an atomic weight of 220. The specific gravity of this oxide is 9.2. Carolinium oxide is soluble in hydrochloric acid. Neither of the other oxides, nor the original thorium oxide, is soluble in this acid. All the oxides show radio-activity. Several chemical differences were also noted. The speaker carefully stated that the materials were not yet in the state of purity that was desired. He stated that none of these substances gave absorption spectra. Some slight differences had been noted in the arc spectra, but no definite conclusions could be drawn. Samples of the materials had been sent to Sir William Crookes, by request, who is

at present engaged in mapping the spectra in the ultra-violet region. Chemists have agreed to accept an element only when a definite atomic weight and characteristic spark spectrum are had. To be sure such important observations require verification in the hands of others as well.

THE INSECT ENEMIES OF COTTON.

THAT the high price of cotton is partly due to the abundance of certain insect pests in the south is strikingly shown by the two maps, which we reproduce, showing the distribution in Texas of two of the more important insect enemies of cotton. The bollworm has long been known as injurious to cotton, corn and other crops, in foreign countries as well as in the United States. The Mexican cotton boll weevil, at present the most serious menace to cotton culture, has spread northward from Mexico during the past ten years, until now it occupies the greater part of the Texan cotton belt, and has entered Louisiana. Both of these insects live within the boll or carpel of the cotton plant; and at present there is no way of combating them save by cultural methods. The government has appropriated a considerable sum of money for an investigation of these insects, and a number of scientists, under the Department of Agriculture, are now at work in Texas and Louisiana. The present status of



Map showing distribution of cotton boll weevil in the United States in 1903. The heavy line indicates the limit of the region in which the weevils have multiplied to such an extent as to be found in all cotton fields; the remainder of the shaded portion indicates the region in which colonies are known to exist.

MAP OF TEXAS SHOWING REGIONS RAVAGED BY THIS BOLLWORM IN 1903.

this investigation and the means of control which the work of the department has shown to be most feasible are detailed in Farmers' Bulletin No. 189 relating to the cotton boll weevil, and in Farmers' Bulletin No. 191 relating to the cotton bollworm, from which publications the two maps presented herewith are taken.

SCIENTIFIC EDUCATION IN SCHOOLS.

THE council of the Royal Society has adopted and submitted to the universities of the United Kingdom the following resolution:

"That the universities be respectfully urged to consider the desirability of taking such steps in respect of their regulations as will, so far as possible, ensure that a knowledge of science is recognized in schools and elsewhere as an essential part of general education."

The council has also appointed a committee, which has drawn up a statement in regard to the teaching of science in schools, which reads as follows:

"Notwithstanding efforts extending over more than half a century, it still remains substantially true that the public schools have devised for themselves no adequate way of assimilating into their system of education the principles and methods of science. The experience of 'modern sides' and other arrangements shows that it can hardly be expected that, without external stimulus and assistance, a type of public school education can be evolved which, whilst retaining literary culture, will at the same time broaden it by scientific interests. On the other hand, it is admitted that many stu-

dents trained in the recent foundations for technical scientific instruction have remained ignorant of essential subjects of general education.

"The bodies which can do most to promote and encourage improvement in these matters are the universities, through the influence which they are in a position to exert on secondary education. This improvement will not, however, be brought about by making the avenues to degrees in scientific or other subjects easier than at present. Rather, the test of preliminary general education is too slight already, with the result that a wide gap is often established between scientific students careless of literary form and other students, ignorant of scientific method.

"It may be suggested that the universities might expand and improve their general tests, so as to make them correspond with the education, both literary and scientific, which a student, matriculating at the age of 19 years, should be expected to have acquired; and that they should themselves make provision, in cases where this test is not satisfied, for ensuring the completion of the general preliminary education of their students, before close specialization is allowed.

"In particular, it appears desirable that some means should be found for giving a wider range of attainment to students preparing for the profession of teaching. The result of the existing system is usually to place the supreme control of a public school in the hands of a headmaster who has little knowledge of the scientific side of education; while the instructors in many colleges have to deal with students who have had no training in the exact and orderly expression of their ideas.

"Our main intention is not, however, to offer detailed suggestions, but to express our belief that this question of the adaptation of secondary education to modern conditions involves problems that should not be left to individual effort, or even to public legislative control; that it is rather a subject in which the universities of the United Kingdom might be expected to lead the way and exert their powerful influence for the benefit of the nation."

SCIENTIFIC ITEMS.

WE regret to record the deaths of M. Emile Duclaux, director of the Pasteur Institute; of Sir Clement Neve Foster, professor of mining in the Royal College of Mining, London; of Professor A. W. Williamson, the eminent British chemist; of Sir Henry Thompson, the distinguished surgeon; and of Sir Henry M. Stanley, the African explorer.

AT the recent meeting of the National Academy of Sciences members were elected as follows: Professor William Morris Davis, Harvard University Professor William Fogg Osgood, Harvard University; Professor William T. Councilman, Harvard Medical School; Professor John U. Nef, University of Chicago. The foreign associates elected were: Professor Paul Ehrlich, Frankfurt; Professor H. Rosenbusch, Heidelberg; Professor Emil Fischer, Berlin; Sir William Ramsay, London; Sir William Huggins, London; Professor George H. Darwin, Cambridge; Professor Hugo de Vries, Amsterdam; and Professor Ludwig Boltzmann, Vienna. The Draper gold medal was presented to Professor George E. Hale, of the Yerkes Observatory, Wisconsin, for his researches in astrophysics.

THE trustees of the British National Portrait Gallery have received by bequest from the late Mr. Herbert Spencer a portrait of himself, painted by J. B. Burgess, R.A., and a marble bust of himself by Sir J. E. Boehm.—The certificate of incorporation has been filed of the Walter Reed Memorial Association for the purpose of securing funds to erect a monument in Washington City to the memory of the late Walter Reed, major and surgeon U. S. Army. Dr. Daniel C. Gilman is presi-

dent, and General George M. Sternberg, vice-president of the association.

LORD KELVIN has been unanimously elected chancellor of the University of Glasgow in the room of the late Lord Stair.—Professor W. Ostwald gave the Faraday lecture of the Chemical Society at the Royal Institution, London, on April 19. At the close of the lecture he was presented with a medal bearing the image of Faraday, which had been specially struck for the occasion. Cambridge University subsequently conferred on him the degree of doctor of science.—The Bruce Gold Medal of the Astronomical Society of the Pacific has been awarded to Sir William Huggins for distinguished services to astronomy.

DR. JOHN M. CLARKE, paleontologist of the state of New York, has been appointed geologist and director of the State Museum.—Dr. F. S. Earle, assistant curator of the New York Botanical Garden, has resigned to accept the office of director of the new agricultural station in Cuba. The station will occupy a farm and buildings at Santiago de la Vegas, about twelve miles from Havana. The sum of $75,000 has been appropriated for the establishment and maintenance of the station for the first year.—Among the distinguished lecturers at the summer session of the University of California, which begins on June 27, are Professor Svante A. Arrhenius, of the University of Stockholm; Professor Hugo De Vries, of the University of Amsterdam; Sir William Ramsay, of University College, London, and Professor James Ward, of the University of Cambridge.

THE corporation of the Massachusetts Institute of Technology has instructed its executive committee to confer with the Harvard University authorities on the subject of closer relations between the two institutions.—A Massachusetts Zoological Society has been incorporated with a view to establishing a Zoological Park in Boston.